# ECOSYSTEM-HEALTH: APPROACH TO RESTORATION OF WETLAND RESOURCES



## DOCTOR OF PHILOSOPHY

THESIS

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# CONTENTS

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# CERTIFICATE

This is to certify that the thesis entitled "**Ecosystem-Health: Approach to Restoration of Wetland Resources**" embodies the original work carried out by **Ms. Pallavee Tyagi**, and that she has worked under my supervision and guidance for more than 36 months commencing from the date of her application and registration and has actually attended Bundelkhand University, Jhansi (Institute of Environment & Development Studies) for more than 200 days.

The work included in this thesis has not been submitted for the award of any degree or diploma to this University or to any other University or Institution.

July 28, 2008

**(Anil K Gupta)**

# DECLARATION

I hereby declare that this work entitled **Ecosystem-Health: Approach to Restoration of Wetland Resources,** is my original research work done under the guidance of **Dr. Anil Kumar Gupta**, Associate Professor, National Institute of Disaster Management, Delhi, for the award of the degree of **Doctor of Philosophy**.

I further state that no part of this thesis has been submitted to any other University for any degree or diploma.

Palltyagi

**(Pallavee Tyagi)**

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Palltyagi

**Pallavee Tyagi**

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# Introduction

Wetlands are the most productive and biologically rich ecosystems on the earth that play a significant role in the ecological sustainability of a region. Wetlands are the transitional zone between land and water, and comprise lakes, ponds, oxbow lakes, surface waterlogged land, playa, swamps, reservoirs, tanks, abandoned quarries and ash ponds. Wetlands play myriad roles-flood and erosion control, water purification, sediment trapping, pollution and nutrient treatment and ecotourism. Thus wetland systems directly or indirectly support millions of people through their biological, ecological, social, cultural and economic values and provide habitats and support diverse range of biodiversity.

Wetlands form the transitional zone between land and water, where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in and on it (Cowardian *et al.*, 1979). In general wetlands are categorized under two broad categories: Inland (e.g., non-tidal, freshwater wetlands) and coastal (also known as tidal, salt water or estuarine) (Barbier *et al.*, 1997). The Ramsar Convention on wetland in 1971 in Iran defined wetland as "*Areas of marsh, fen, peatland, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters.*"

Two-thirds of the earth is surrounded by water and appears blue (the planet of water) from space (UNEP, 1994). Lakes and rivers, the most important freshwater resources, account for 2.53% of the total water found on earth. Of the total water in the hydrosphere ($4 \times 10^8$ cubic kilometres), 97.5% is deposited in the oceans that cover 71% of the earth's surface. Wetlands are estimated to occupy nearly 6.4% of the earth's surface, 30% of which is made

up of bogs, 26% fens, 20% swamps, about 15% flood plains, etc. (IUCN, 1999). The amount of fresh water on earth is very small compared to seawater, of which 69.6% is locked away in the continental ice, 30.1% in underground aquifers, and 0.26% in rivers and lakes. Lakes in particular occupy less than 0.007% of the world's fresh water.

## Wetlands: Indian Scenario

India is blessed with rich diversity of wetland resources due to its geographical position, changing topography and climatic conditions. India has total 67,429 wetlands, covering an area of about 4.1 million hectares (MoEF, 1990). Out of these, 2,175 are natural wetlands occupying an area of 1.5 million hectares and 65,254 man-made wetlands with 2.6 million hectares area. Out of the total area 0.45 million hectares is covered by mangroves. Wetlands in India (excluding rivers), account for 18.4% of the country's geographic area, of which 70% is under paddy cultivation. About 80% of the mangroves are distributed in the Sunderbans of west Bengal and Andaman and Nicobar Islands, with rest in the coastal states of Orissa, Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Goa, Maharashtra and Gujarat.

In India, inland water bodies are distributed from the cold arid Trans-Himalayan zone to wet Terai regions of Himalayan foothills and Gangetic plains extending to the floodplains of Brahmaputra and swamps of northeastern India including the saline expanses of Gujarat and Rajasthan. Along the east and west coasts they occur from the deltaic regions to the wet humid zones of Southern peninsula and beyond, to the Andaman and Nicobar and Lakshadweep Islands. There are several wetlands being shared with neighbouring countries too as in case of Ladakh and Sunderbans. The major river basins of the country are the Ganges, Brahmaputra, Narmada, Tapti, Godavari, Krishna and Cauvery.

The predominant wetland types in India's geographical zones are as follows (Scott, 1989):

- The reservoirs of the Deccan Plateau in the south, together with the lagoons and other wetlands of the southwest coast
- The vast saline expanses of Rajasthan, Gujarat and the Gulf of Kutch
- The freshwater lakes and reservoirs from Gujarat eastwards through Rajasthan (Keoladeo Ghana National Park) and Madhya Pradesh
- The delta wetlands and lagoons of India's east coast (Chilka Lake)
- The freshwater marshes of the Gangetic Plains and the floodplains of the Brahmaputra
- The marshes and swamps in the hills of northeast India and the Himalayan foothills
- The lakes and rivers of the mountain region of Kashmir and Ladakh
- The mangroves and other wetlands of the Andaman and Nicobar Islands

According to the *Directory of Asian Wetlands* (1989), wetlands occupy 58.2 million hectares or 18.4% of the country's area (excluding rivers), of which 40.90 million hectares (70%) are under paddy cultivation. Estimates of the types of wetlands in India and the total area covered by them are given in **Table 1.1.**

A preliminary inventory by the Department of Science and Technology in India, recorded a total of 1,193 wetlands, covering an area of about 3,904,543 ha, of which 572 were natural (Pole *et al.*, 1989). The Directory of Indian Wetlands published by WWF and Asian Wetland Bureau in 1995 records 147 sites as important of which 68 are protected under the National Protected Area Network by the Wildlife Protection Act of 1972. State-wise distribution of wetlands in India (Chatrath, 1992) is given in **Table 1.2**.

India has a total of 25 Ramsar sites covering an area of 648,507 ha. Many of the sites qualify on hydrological grounds, many for their birds and some for their sea turtles, others for their support for fisheries, and a few are considered to be sacred in one way or another. Under the national wetland conservation programme, 68 wetlands have been identified across India (MoEF, 2000).

**Table 1.1: Area covered by different types of wetlands in India**

| Sl. No. | Wetland Types | Area (in million ha.) |
|---|---|---|
| 1 | Area under paddy cultivation | 40.9 |
| 2 | Area suitable for fish culture | 3.6 |
| 3 | Area under capture fisheries (brackish & freshwater) | 2.9 |
| 4 | Mangroves | 0.4 |
| 5 | Estuaries | 3.9 |
| 6 | Backwater | 3.5 |
| 7 | Man-made impoundments | 3.0 |
| 8 | Rivers, including main tributaries | (28,000 km) |
| 9 | Canals and irrigation channels | (113,000 km) |
| 10 | Total Area of Wetlands (Excluding Rivers) | 58.2 |

Source: Directory of Asian Wetlands, IUCN, 1989

**Table 1.2: Distribution of wetlands in India**

| Sl.No | State | Natural | | | Artificial |
|---|---|---|---|---|---|
| | | Nos. | Area (ha) | Nos | Area (ha) |
| 1 | Andhra Pradesh | 219 | 1,00,457 | 19,020 | 4,25,892 |
| 2 | Arunachal Pradesh | 2 | 20,200 | NA | NA |
| 3 | Assam | 1394 | 86,355 | NA | NA |
| 4 | Bihar | 62 | 2,24,788 | 33 | 48,607 |
| 5 | Goa | 3 | 12,360 | NA | NA |
| 6 | Gujarat | 22 | 3,94,627 | 57 | 1,29,660 |
| 7 | Haryana | 14 | 2,691 | 4 | 1,079 |
| 8 | Himation Pradesh | 5 | 702 | 3 | 19,165 |
| 9 | Jammu and Kashmir | 18 | 7,227 | NA | 21,880 |
| 10 | Karnataka | 10 | 3,320 | 22,758 | 5,39,195 |
| 11 | Kerala | 32 | 24,329 | 2,121 | 2,10,579 |
| 12 | Madhya Pradesh | 8 | 324 | 53 | 1,87,818 |
| 13 | Maharashtra | 49 | 21,675 | 1,004 | 2,79,025 |
| 14 | Manipur | 5 | 26,600 | NA | NA |
| 15 | Meghalaya | 2 | NA | NA | NA |
| 16 | Mizoram | 3 | 36 | 1 | 1 |
| 17 | Nagaland | 2 | 210 | NA | NA |
| 18 | Orissa | 20 | 1,37,022 | 36 | 1,48,454 |
| 19 | Punjab | 33 | 17,085 | 6 | 5,391 |
| 20 | Rajasthan | 9 | 14,027 | 85 | 1,00,217 |
| 21 | Sikkim | 42 | 1,107 | 2 | 3 |
| 22 | Tamil Nadu | 31 | 58,068 | 20,030 | 2,01,132 |
| 23 | Tripura | 3 | 575 | 1 | 4,833 |
| 24 | Uttar Pradesh | 125 | 12,832 | 28 | 2,12,470 |
| 25 | West Bengal | 54 | 2,91,963 | 9 | 52,564 |
| | **TOTAL** | 2167 | 14,58,580 | 65,251 | 25,87,965 |

| Sl.No | Union Territories | Natural | Area (ha) | Nos | Artificial Area (ha) |
|---|---|---|---|---|---|
| 1 | Chandigarh | -- | -- | 1 | 170 |
| 2 | Pondicherry | 3 | 1,533 | 2 | 1,131 |
| | **TOTAL** | 3 | 1,533 | 3 | 1,301 |
| **GRAND TOTAL** | | 2,170 | 14,60,113 | 65,254 | 25,89,266 |

Source: Chatrath, 1992

## Wetland Functions and their Values

In the 1970', scientists, ecologists, and conservationists began to articulate the values of wetlands. At a wetland conference in 1973, wetlands were acknowledged to be an important part of the hydrologic cycle (Helfgott and others, 1973). In 1977, participation at the first National Wetland Protection Symposium-attended by more than 700 people demonstrating a growing interest in the value of wetlands and the need to protect them (Kusler *et al.*, 1978). At a Wetland Values Management Conference in 1981, scientists defined the unique qualities of wetlands and developed a list of wetland functions (Richardson, 1981). In addition to the more commonly recognized habitat functions of wetlands, the scientists described hydrologic and water-quality functions. During the 1980's participants at many more conferences and symposia expanded the understanding and appreciation of the values of wetlands (Kusler *et al.*, 1986).

Thus public recognition of the value of wetlands has risen rapidly over the past 25 years. Wetland functions are defined as a process or series of processes that take place within a wetland. Wetlands have several major functions: 1) biologic diversity/integrity; 2) water storage; 3) water exchange between surface water and ground water; 4) surface water filtration; 5) vapor and gas exchange with the atmosphere; 6) chemical attenuation and transformation. The functional capacity of a wetland is determined by characteristics of the wetland ecosystem such as hydrologic regime, plant species composition, and soil type, and the larger systems that surround it (Forman *et al.*, 1986). Natural wetlands are quite variable, thus the capacity of a given wetland to perform a given function also is variable (Bruce *et al.*, 2006).

Wetlands have value because their functions have proved to be useful to humans value increases with increased use/increased scarcity (Mitsch *et al.*,

2000). Wetland functions have value on several levels- internal, local, regional and global. Thus wetland ecosystems are part of our natural wealth. A recent assessment of our natural ecosystems estimated them at US$ 33 trillion. The study estimated the global value of wetland ecosystems at an amazing US$ 14.9 trillion, 45 percent of the total (IUCN). The recent ecosystem study valued the ecosystem services of different wetland types, as defined by the Ramsar Convention, as follows:

| **Wetland Type** | **Total value (US$) per hectare per year** | **Total global flow value (US$ per year)** |
|---|---|---|
| Seagrass/algae beds | 19,004 | 3,801,000,000,000 |
| Coral reefs | 6,075 | 375,000,000,000 |
| Tidal marsh/mangroves | 9,990 | 1,648,000,000,000 |
| Swamps/flood plains | 19,580 | 3,231,000,000,000 |

*Taken from Costanza *et al.* 1997. The value of the world's ecosystem services and natural capital. *Nature* **387**, 253-260.
**The figures above exclude the study's "continental shelf" category since only part of this would be defined as wetland under the Ramsar Convention.

While the study acknowledged that this is a first approximation to valuing ecosystem services, the authors also consider it to be a minimum estimate. A dollar value on wetland functions is powerful ammunition to convince decision-makers that wetlands should be conserved and wisely used.

## Status of wetland loss in India

Wetlands are fragile ecosystems and are susceptible to changes even with little change in its composition of biotic and abiotic factors. In recent years, there has been increasing concern over the continuing degradation of wetlands and in

particular, rivers and lakes. The major activities responsible for this wetland loss are urbanization, drainage for agriculture and water system regulation (IUCN, 1999). Development activities like excavation, filling, draining etc. are the major destructive methods resulting in a significant loss of wetland acreage throughout the country. The impact on wetlands may be grouped into five categories: loss of wetland area, changes to water regime, changes in water quality, overexploitation of wetland products and introduction of exotic or alien species (Ramachandra, 2001).

Though accurate results on wetland loss in India are not available, the Wildlife Institute of India conducted a survey on these aspects and revealed that 70 – 80 percent of individual fresh water marshes and lakes in the Gangetic flood plains have been lost in the last five decades. At present, only 50 percent of India's wetlands remain. They are being lost at a rate of 2 to 3% every year. Indian mangrove areas have been halved almost from 700,000 hectares in 1987 to 453,000 hectares in 1995 (Sustainable Wetlands, Environmental Governance-2, 1999). The Directory of Indian Wetlands published by the World Wide Fund for Nature (WWF)-India and Asian Wetland Bureau in 1995 records 147 wetland sites. About 32% of these sites were lost primarily through hunting and associated disturbances, while 22% were lost to human settlements, 19% to fishing and associated disturbances, and 23% through drainage for agriculture. Removal of vegetation in the catchment leads to soil erosion and siltation that is estimated to contribute to over 15 % of wetland loss. Nearly 20 % of wetlands have been lost mainly due to pollution from industries (WCMC, 1998). The loss of wetlands leads to environmental and ecological problems, which have a direct impact on the socio-economic benefits of the associated populace. As wetlands provide various direct and indirect values to society through different processes accompanied with them.

Jhansi, the walled city grew up in 1613, regionally, falls in Uttar Pradesh part of Bundelkhand and is close to counterparts in Madhya Pradesh. Total number of wetlands in Jhansi district as reported by SAC, ISRO, is 16, covering an area of 5127.47 hectares. Predominant wetland types are man-made lakes and reservoirs/tanks, historically noted among those are Lakshmital, Antiatal and Baruasagar Lake. Two of them lay in the Jhansi city itself i.e. Antiatal and Lakshmital.

Lakshmital situated outside the city wall in the direction of Kaimasan Hill, covers an area of 32.52 hectares with an average depth of 2.5 meter. It lies between longitude of $78^0$ $37^1$ E and $25^0$ $57^1$ N of latitude and has a catchment area of 2370 hectares having a storm water intensity of nearly 0.75 per hour/acre of flood rain. It is a rain fed water body. It is a beautiful lake surrounded by little hillocks. Topping these hillock and around the lake there are twelve temples built in similar design, some of them are in the vicinity of the taal. The sight of Lakshmital with the temples all around is enchanting and a reminder of the architectural skills of the builders and shows its religious importance. Adjoining the Lakshmital there is a Narayan Bagh, famous garden of Jhansi. Any time of the day the atmosphere here is a cool peaceful and serene. The lake possesses economic, ecological and aesthetic values to society. But like many other water bodies in India, Lakshmital is also under ecological crisis due to a number of urban anthropogenic activities. Lakshmital presently received 06 channels of municipal sewage and runoff from the surrounding area covering the watersheds of the Lakshmital carries numerous waste and pollutants. Defecation and waste disposal aggravated the problem. Earlier there were bathing and washing ghats which are non-functional now due to highly degraded quality to lake water. Apart from these activities, a number of other natural processes like decomposition of dead leaves and plants residues, siltation etc., also cause degradation in lake quality.

## Objectives

Keeping all the above discussed views in consideration, the current study entitled **"Ecosystem-Health: Approach to Restoration of Wetland Resources"** has been undertaken with the following objectives:

- Identification of most appropriate indicators for ecosystem health for wetland-system components.
- Assessment of physico-chemical characteristics of Lakshmital Lake in different seasons and observation of significant correlations between them in different seasons and in annual mean.
- Assessment of metals concentration in lake water, sediments and in macrophytes, and calculation of their significant correlation coefficients.
- Identification and assessment of macrophytes in Lakshmital with reference to phytoremediation mechanisms.
- Assessment of socio-economic pressures on the lake ecosystem of Lakshmital and evaluation of its wetland potential for specific use-values and functions.
- Development of specific planning and restoration strategy for sustainable and cost-effective management of Lake Lakshmital.

The outcome of present study would help and assist the lake mangers in their efforts to effectively restore and rehabilitate the lake ecosystem.

# Review of Literature

## Wetland ecosystems

Tansley (1935), defined ecosystem, "*A fundamental organizational unit of the natural world that includes both organisms and their spatial environment.*" Ecosystems have since been defined in various ways, and at different spatial and temporal scales (Evans 1956; O'Neill *et al.* 1986; Golley 1993). From an anthropocentric viewpoint all ecosystems can be classified in terms of their structural and functional aspects (Westman, 1985; Turner, 1988; Barbier, 1989). In this line Lindeman (1942) defined ecosystems as "*...the system composed of physical, chemical, and biological processes active within a space/time unit.*" Rowe (1961) defined ecosystems as "*...a three dimensional segment of the earth where life forms and the environment interact*", emphasizing the concept of integral relation of biotic components with abiotic characteristics and processes of ecosystems. Bormann *et al.* (1969) defined that ecosystems are normally characterized in terms of their structural components and the processes that link these components. Hutchinson (1978) considered the ecosystem to be the environmental context in which population or community dynamics occur. Rowe *et al.* (1994) defined ecosystems in terms of their abiotic characteristics and processes.

Aquatic ecosystem is an ecosystem located in a body of water in which communities of organisms that are dependent on each other and on their environment live together. The two main types of aquatic ecosystems are marine ecosystems and freshwater ecosystems (Alexander, 1999). Marine ecosystems cover approximately 71% of Earth's surface and contain approximately 97% of the planet's water. Freshwater ecosystems cover 0.8% of

the Earth's surface and contain 0.009% of its total water. There are three basic types of freshwater ecosystems (Vaccari, 2005):

*Lentic:* slow-moving water, including pools, ponds and lakes;

*Lotic:* rapidly-moving water, for example streams and rivers.

*Wetlands:* areas where the soil is saturated or inundated for at least part of the time.

Wetland ecosystems have been defined in a variety of ways by researchers, resource managers, and regulatory authorities, depending on their specific needs and objectives (Mitsch *et al.* 1993). As per definition adopted at Ramsar Convntion (Iran in 1971), *"Wetlands are areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including areas of marine water the depth of which at lowtide does not exceed 6-m"*. Sanjappa (2001) defined wetlands, important ecotones between open waters and terrestrial systems; those are endowed with specific structural and functional attributes executing unique ecological roles. Cowardin *et al.* (1979) opined that wetlands form the transitional between land and water, where saturation with water is the dominant factor determining the nature of soil development and the types of plants and animal communities living in and on it. According to Mitch *et al.*, 1986, wetlands are the lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water. They considered wetlands as *"Kidneys of the landscape"*. The term 'Wetland' groups together a wide range of habitats that share common features including continuous, seasonal or periodic standing water or saturated soils (Finlayson *et al.*, 1999). Ismail *et al.* (2005) called wetlands, "in between world"- between upland terrestrial ecosystem and deep water aquatic systems.

The importance and usefulness of wetlands was first brought to the notice of the world through a Convention on Wetlands held at the Iranian city Ramsar, in the year 1971. India's wetlands are generally differentiated into eight categories depending on their regional presence (Scott, 1989). A preliminary inventory by the Department of Science and Technology, recorded a total of 1,193 wetlands, covering an area of about 3,904,543 hectares, of which 572 were natural (Scott *et al.*, 1989). MoEF, 1990 made an attempt that India has totally 67,429 wetlands, covering an area of about 4.1million hectares, out of these 2,175 are natural with an area of 1.5 million hectare and 65,254 are man-made with an area of 2.6 million hectares. The Directory of Indian Wetlands published by WWF and Asian Wetland Bureau in 1995 records 147 sites as important of which 68 are protected under the National Protected Area Network by the Wildlife Protection Act of 1972. IUCN in 1996, recorded that wetlands with a share of 0.0001% among the global water sources include swamps, marshes, bogs and similar areas and are an important and vital component of the ecosystem. According to MoEF (2000), India has a total of 25 Ramsar sites covering an area of 648,507 hectares.

## Structure and Functions of Wetlands

Ecosystem functions are the result of interactions between structure and processes. They include such actions as flood water control, nutrient retention and food web support (Maltby *et al.*, 1996). Novitzki *et al.*, (1997) defined wetland functions, as a process or series of processes that take place within a wetland. During the 1980s, participants at many more conferences and symposia expanded the understanding and appreciation of the values of wetlands (Kusler *et al.*, 1986). Richardson, 1981, explained at a wetland values and management conference that scientists defined unique qualities of wetlands and developed a list of wetland functions. The functional capacity of a wetland

is determined by characteristics of the wetland ecosystem such as hydrologic regime, plant species composition, and soil type, and the larger systems that surround it (Forman *et al.*, 1986). According to Zedler (2003), wetlands contribute as much as 40% of the earth's renewable ecosystem services, even though they cover only 1.5% of the planet's surface.

Values are "an estimate, usually subjective, of worth, merit, quality, or importance" (Richardson 1994). Wetland "values" may derive from outputs that can be consumed directly, such as food, recreation, or timber; indirect uses which arise from the functions occurring within the ecosystem, such as water quality, and flood control; possible future direct outputs or indirect uses such as biodiversity or conserved habitats; and from the knowledge that such habitats or species exist (known as existence value) (Serageldin, 1993). Brinson (1993) developed a hydrogeomorphic classification for use in evaluating wetland function. Smith *et al.* in 1995, outlined an approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices. According to Edward *et al.* (1997) opinion to aid and improve wise use and management of wetland resources, economic valuation aids as a powerful tool for measuring and comparing the various benefits of wetlands.

Wetlands due to their biological, ecological, social, cultural and economic values form an important component of the environment (Edward *et al.,* 1997). Wetlands can abate flooding, improve water quality, and support biodiversity (Neely *et al.,* 1989; Crumpton *et al.,* 1993; Richardson *et al.,* 1993; Bedford 1999; Keddy 2000). Both direct and indirect socio-economic benefits are derived from functioning ecosystems – food, fiber, fuel, pharmaceuticals and services such as climate regulation, water purification, soil formation, flood protection and nutrient cycling, aesthetic and cultural benefits are also

important in this contact (Costanza *et al.,* 1997; Daily, 1997; Balmford *et al.* 2002; Turner *et al.* 2003). A fundamental requirement, however, remains the need for a functional classification of wetlands and considerable scientific effort is now being directed towards that goal (Simpson *et al.,* 1998). Rajnikant *et. al.,* 2004, viewed that the economic valuation of wetlands helps to understand the constituent's functions and benefits.

Lapedes, 1976, defined 'Habitat' as the part of the physical environment in which plants and animals live, and wetlands are among the most productive habitats in the world (Tiner, 1989). Mafabi (1995) defined wetlands as places where water stays long enough for plants and animals to become adapted to waterlogged conditions. Wetlands in Asia (1997), estimated that about 20% of the known species of life rely directly or indirectly on wetlands for their survival, as they are their primary and important seasonal habitats.

At a wetland conference in 1973, wetlands were acknowledged to be a important part of the hydrologic cycle (Helfgott, 1973). According to Balek (1983), the volume of run-off decreases in a catchment as the percentage area of wetlands increases. Hence wetlands play a key role in mitigating and responses to rainfall and ensuring the longer residence of water in the catchment. Thus wetlands may also act to moderate temperature extremes in adjacent uplands (Brinson 1993). Wetlands are an important part of hydrological systems. They function as sponges that store water during the wet season and maintain baseflows during drier periods of the year (Balek *et al.,* 1973; Dugan, 1990; Roggeri, 1998). Climate control is another hydrologic function of wetlands as many wetlands return over two thirds of their annual water inputs to the atmosphere through evapotranspiration (Richardson *et al.*, 1994). Mitsch *et al.* 1993; Richardson (1994), considered critical role of wetlands in regulating the movement of water within watersheds as well as in the global water cycle.

Adams, 1993a; Scoones, 1991, explained wetlands, the areas, especially important in the dry parts of developing countries where they have a strategic importance for rural livelihoods out of all proportion to their size. Muthuri, 1993, conducted a study that traditionally wetlands have been used as a source of forage resource for the construction of fishing boats and houses as well as for the local crafts. Wetlands with a share of 0.0001% among the global water sources include swamps, marshes, bogs and similar areas and are an important and vital component of the ecosystem (IUCN, 1996). Denny in 1997, find out that most wetlands are a critical source of drinking water for rural communities, as a result of their ability to purify contaminated water, both chemically and biologically. Park (1997) opined that the lakes contribute globally 0.088% to freshwater resource, which is generally available for drinking and domestic purposes.

Participatory research with communities revealed that wetland farmers possess extensive and accurate knowledge of the hydrological dynamics of the wetland system, which includes a detailed understanding of the relationship between rainfall, runoff and water table levels (Dixon, 2000). Ewaschuk *et al.,* (2001) conducted a study about the value of wetlands for agricultural procedures in the Central Parkland Region of Alberta. Donovan *et. al.* in 2000 conducted a study on wetlands and water quality enhancement. Adams (1992) and Potgieter (2002) described the functions and value of wetlands in protecting water quality. A wetland's effectiveness in improving water quality depends on hydrologic patterns, amount and type of vegetation, time of year, and the constituent of concern (Zedler and others, 1985). According to Hammer, 1992; Hemond and others 1987, the water purification functions of wetlands are dependent upon four principal components of wetland- substrate, water, vegetation and microbial populations. Wetland soils are the medium in which many of the wetland chemical transformations occur and the primary storage

area of available chemicals for most plants ((Mitsch *et al.*, 1993). Ground water and surface water transport sediments, nutrients, trace metals, and organic materials. Wetlands can trap, precipitate, transform, recycle and export many of these waterborne constituents, and water leaving the wetland can differ markedly from that entering (Mitsch *et al.*, 1993; Elder, 1987).

Pollutants that impact water quality such as nutrients, organics, metals and radionuclides are often adsorbed onto suspended solids. Deposition of suspended solids, to which such substances are adsorbed, removes these pollutants from the water. Thus sediment deposition provides multiple benefits to downstream water quality (Johnston 1991; Hemond *et al.* 1988; Hupp *et al.* 1993; Puckett *et al.* 1993). Seidel, 1970; Rogers, 1983, stated several factors may be responsible for the depletion of bacteria and viruses in wetland waters. These include adsorption onto sediments and subsequent sedimentation, exposure to solar radiation, and the presence of toxic substances such as root secretions which have been shown to kill pathogenic bacteria.

According to Hammer, 1992, wetlands reduce shoreline erosion by stabilizing sediments and absorbing and dissipating wave energy. Typically wetland vegetation traps 80-90% of sediment from runoff (Gilliam 1994; Johnston 1991). Less than 65% of the sediment eroded from uplands exits watersheds that contain wetlands (Johnston 1991). A chemical mass balance study was conducted in Beriah swamps, a tropical fresh water swamp in north Perak, Malaysia, aimed at investigating the role and function of wetlands in filtering sediment and retaining sediment or nutrient (Ismail *et al.,* 2005)

Metal removal efficiencies can vary greatly depending on the particular metal and wetland types involved (Tchobanoglous *et al.,* 1980). Wetlands remove 20%-100% of metals in the water, depending on the specific metal and the

individual wetland (Taylor *et al.* 1990). Certain wetlands play an important role in removing metals from other water resources, runoff, and ground water (Owen 1992; Gambrell 1994; Puckett *et al.* 1993). Observations show that both natural and artificial wetlands have a capacity to purify wastewater containing heavy metals (Matagi, 1993; Tam *et al.,* 1994; Mbeiza, 1993; Denny *et al.,* 1995).

Scientists have estimated that wetlands may remove between 70% and 90% of entering nitrogen (Reilly 1991; Gilliam 1994). The estimated mean retention of phosphorus by wetlands is 45% (Johnston 1991). Wetlands remove BOD from surface water through decomposition of organic matter or oxidation of inorganics that may approach 100% (Hemond *et al.,* 1998).

Wetlands can provide cost-effective flood control, and in some instances their protection has been recognized as less costly than flood control measures such as reservoirs or dikes (Carter and others, 1979). A recent study in the USA estimated that 0.4 hectares of wetland can store over 6,000 cubic meters of floodwater (RCB, 2000). Ismail *et al.*, 2005, opined that slowed down of runoff entering a wetland may be due to the spread of floodwater over a large area; its immobilization in low-lying basins and depressions or the moderating effects of the vegetation (e.g. swamp vegetation).

## Ecosystem health of Wetlands

More than 50,000 small and large Indian lakes are polluted to the point of being considered 'dead' (Chopra, 1985). Urban water bodies receiving external pressure from human settlements adversely affect nearby aquatic ecosystems (Khan, *et al.,* 1988). The loss or importance of wetland ecosystem is usually accompanied by irreversible loss in both the valuable environmental functions

and amenities important to the society (Zentner, 1988). According to Scott (1989) about 50,000 hectares area of wetlands is degraded every year in Asia.

Narayanan, 1992, revealed that about 50% of the world's wetlands have been lost in the last century, primarily through drainage for agriculture, urban development and water system regulations and it has been estimated that nearly one hectare of the world's wetlands is getting degraded at the tick of every minute of the clock. Lee *et al.*, 1996, observed that the loss of one square kilometer of wetlands in India will have much greater impacts than the loss of one square kilometer of wetlands in low population areas of abundant wetlands. Singh, Pathak *et al.*, 2002, estimated that water resources in India have reached a point of crisis due to unplanned urbanization and industrialization.

Wetlands and pollution wetlands are recognized as areas where water is the dominant factor determining development of soils and associated biological communities and where, at least periodically, the water table is at or near the surface (Smith, 1989; Jenssen, *et al.*, 1993). The important issues concerning aquatic systems are soil erosion, weed infestation, human encroachment, pollution and aquaculture (Kaul, 1995). The washing of large amount of clothes by dhobis, laundry workers, and the continued entry of domestic sewage in some areas are posing pollution problems (Benjamin *et al.*, 1996). Cooke *et al.*, in 1990, observed changes in the water, soil, and vegetation of a wetland after a decade of receiving a sewage effluent.

Ladhar (2002) investigated the status of ecological health of wetlands in Punjab, India. Zafaralla (2002) assessed the ecological status of Lake Laguna de Bay, Philippines. Chandrashekar *et al.* (2003) assessed the impact of urbanization on Bellandur Lake, Bangalore as a case study. TSPCB, 2003,

conducted a study about pollution status assessment of Hrishidas Colony Pond, Pratapgarh.

Heavy metals in surface water systems can be from natural or anthropogenic sources but currently, anthropogenic inputs of metals exceed natural inputs. Driel *et al.* (1974) and Bower *et al.*, (1978) have studied the metal uptake, translocation and effects in plants growing on naturally polluted and unpolluted sediments. The effects of trace elements in an aquatic ecosystem can be assessed by changes in the community structure, physiological activity and ultrastructural components of macrophytes (Chester and Stoner, 1974; Bohn, 1975; Pulich *et al.*, 1976; Bradford, 1976). High levels of Cd, Cu, Pb, Fe can act as ecological toxins in aquatic and terrestrial ecosystems (Guilizzoni, 1991; Balsberg - Pahlsson, 1989).

Recent studies have shown the bioaccumulation and biomagnification of different toxic metals in the wetland environment of India (Sharma *et al.*, 1990; Saxena *et al.*, 1991; Fender *et al.*, 1992; Madhappan, 1993; Rao *et al.*, 1993; Mehta *et al.*, 1996; Sharma *et al.*, 1996; Rema *et al.*, 1997; Thaker *et al.*, 1997). Cairns *et al.* (1994) estimated the effects of toxicants on ecosystem services. Pani *et al.*, 2000, identified that in last two decades in most of the tropical urban water bodies there has been an alarming elevation in the concentration of heavy metals due to various anthropogenic activities in and around the waterbodies. Consumption of such aquatic food stuff enriched with toxic metals may cause serious health hazards through food-chain magnification (Khan *et al.*, 2000). Thus occurrence of toxic metals in pond, ditch and river water affect the lives of local people that depend upon these water sources for their daily requirements (Rai *et al.*, 2002). Chattopadhyay *et al.* (2002) examined the extent of toxic metal contamination of the east Calcutta wetland ecosystem.

According to Vollenweider (1976), the concept of nutrient overloading has a great impact on all subsequent eutrophication research and lake management. Marsden, 1989, described eutrophication, the variations in aquatic systems due to nutrient enrichment; the eventual consequence of that enrichment is the growth of primary production to nuisance proportions. Storm water runoff and discharge of sewage into the lakes are two common ways that various nutrients enter the aquatic ecosystems resulting in the death of those systems (Sudhira *et al.,* 2000). Phosphate is considered to be the most significant among the nutrients responsible for eutrophication of lakes, as it is the primary initiating factor (Dixit, *et al.*, 2005).

It has been shown that the eutrophication results in a number of changes in the floristic composition, species diversity and primary production of the water bodies, besides several phyisco-chemical changes (Hasler 1947; Edmondson 1961; Vollenweider 1968; Palmer 1969; Morgan 1972; Moss 1973a; Scindler 1974; Stoermer *et. al.* 1978). In India Munawar (1970, 1974a,b) and Zafar (1964, 1967) have done detailed studies on the lakes in Hyderabad and found most of them to be eutrophicated due to human activities. Ganpati (1972) has presented a detailed account of primary productivity in enriched water in South India. Extensive investigations on Kashmir lakes by Kaul (1977), Zutshi *et al.* (1978) and Shashikant *et al.* (1975) have revealed destruction of beautiful lakes due to increasing anthropogenic interferences. Water bodies in Jaipur are also facing severe problems of pollution by domestic and industrial sewage (Sharma *et al.,* 1978). Khagan *et al.* (1996) discussed the effect of pH on the removal of metal ions from solutions. Stumm (1996) reported that most chemical processes in aquatic systems occur at the surface of minerals and inorganic and organic particles.

## Health Indicators

Limnology is the study of lake systems and their deposits. *"Limno"* is based on the Greek word *"Limne"* meaning marsh, lake or pool. Limnology is the study of freshwater communities which includes chemical parameters, physical features, and biological structure (LPL, 2005). Welch (1935) has written a book entitled 'Limnology' gives due considerations to different aspects of physico-chemical as well as biological limnology. Health indicators can be categorized under three groups, viz. (A) physico-chemical, (B) biological, (C) ecological.

### A. Physico-chemical:

According to Ismail *et al.* (2005) the water chemistry of wetlands is primarily a result of the geologic setting, water balance i.e. relative proportion of inflow, outflow and storage, quality of inflowing water, types of soils and vegetation, and human activities within or near the wetland. Hydrological conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties, and pH. These modifications of the physicochemical environment, in turn, have a direct impact on the biotic response in the wetlands (Gosselink *et al.*, 1978). USEPA, 1994, examined the primary pollutants causing degradation are sediments, nutrients, pesticides, salinity, heavy metals, weeds, low dissolved oxygen, pH and selenium.

In India for the first time attempt was made by Prasad (1916) to study aquatic life in relation to climatic conditions, in a pond of Punjab. Pruthi (1933) has studied the seasonal and diurnal variations in the physico-chemical conditions of a tank at Calcutta museum compound. Hutchinson (1957, 67, 75), Hynes (1972) Golterman (1975), Wetzel (1975), Reid *et al.* (1976), Cole, (1979)

Goldman *et al.* (1983), have worked on physico-chemical characteristics of standing water with respect to surrounding environment. Barker (1970) determined the phsico-chemical features of Lake Pupuke, Auckland. Gengerke *et al.* (1972) studied the physical-chemical limnology of a South Dakota farm pond. Agarker *et al.* in 1994, studied water quality of Bhoj wetland in Bhopal. Evans *et al.* (1996) carried out a study on wetlands and water quality.

Jain *et al.*, 1996, carried out a limnological study of Kayamkulam Lake. Limnological studies of lakes and reservoirs have been carried out by Singh *et al.* (1997) and Jain *et al.* (1998). Analysis of drinking water quality in Gavinath pond Birsinghpur was carried out for various physico-chemical characteristics by Tripathi *et al.* in 1999. Mitchell (1999) assessed water quality in Sylvan Lake. A Study has been undertaken by Srivastava *et al.* in 2002 to evaluate physico-chemical parameters (pH, temperature, dissolved oxygen, free carbon dioxide, alkalinity and hardness) and zinc concentration in water bodies in and around Jaipur. Muri *et al.* (2003), analyzed the water quality in three Slovenian Mountain Lakes situated in the Julian Alps, NW Slovenia. Muri, 2004, determined the physico-chemical characteristics of the water in 14 Slovenian mountain lakes. ENPHO (2006) monitored the water quality states of Phewa Lake. Devi (2006) observed the chemical status of Loktak Lake. Das *et al.* (2007) carried out a limnological survey of three tropical water reservoirs in Eastern India.

Colour of lake water can also affect water clarity because of dissolved organic compounds. Sources of colour commonly originate from the decomposition of naturally occurring organic matter. In a water body pH controls the chemical state of many nutrients including dissolved oxygen, phosphate, nitrate etc. (Goldmann *et al.,* 1983). At a given temperature pH is controlled by the dissolved chemical compounds and the biological processes in the solution

(Chapman, 1996). The higher values of pH may be due to the increased primary production in aquatic ecosystem of lake (Zafar, 1996 and Mussaddiq *et al.*, 2001) and also the high rate of photosynthetic activity will raise the pH (Parkins 1976).

The conductivity reflects the level of water salinity (Moiseenko *et al.*, 1996). According to Garg (1998) a number of bases, viz. carbonates, bicarbonates, hydroxides, phosphates, nitrates, silicates, borates etc., contribute to alkalinity. Wetzel, 1973 recommended 8 mg/l dissolved oxygen concentration for a healthy and ideally productive lake. Reductions in DO concentrations can be caused by the decomposition of organic wastes and the oxidation of inorganic waste (Mc Neely *et al.*, 1979). BOD is directly linked with decomposition of dead organic matter present in the lake and hence the higher values of BOD can be directly related with pollution status of the lake (WQM, 1999).

According to Jain *et al.*, 1997, the lake water is characterized by very high concentration of chlorides, calcium and magnesium so the total hardness of any water is dependent on these factors. Chloride concentration indicates the presence of organic waste, primarily of animal origin (Thresh *et al.*, 1949). The presence of chloride concentration in a water source is used as an indicator of organic pollution by domestic sewage (NEERI, 1979). Saxena, 1998, explained that the disposal of both suspended and dissolved solids leads to sedimentation. Wetlands have been identified as significant storehouses (sinks) of carbon. Using Ramsar's broad definition of wetlands this amount to as much as 40% of global terrestrial carbon (RCB, 2000).

Van der Valk *et al.* (1979) list the results of 17 different studies investigating the potential of wetlands to act as nitrogen and phosphorus sinks. Adamus *et al.,* 1987, opined that nitrogen and phosphorus are the nutrients most commonly

identified as pollutants. Hemond *et al.,* 1988, revealed that freshwater wetlands receive nitrogen and phosphorus from natural sources, such as runoff from vegetated watersheds, and anthropogenic sources, such as effluent discharge, and runoff from fertilized cropland. Levels of total nitrogen (TN) and total phosphorus (TP) in lakes can be influenced by a complex set of biogeochemical processes (e.g. sedimentation, nitrification, denitrification and fixation etc; Seitzinger 1988). Edmondson in 1991, opined that nutrient enrichment led to eutrophication of water bodies.

Nitrogen and Phosphorus are significant contributors to eutrophication of waterbodies (Carpenter *et al.*, 1998). Eutrophication can result in decreased oxygen levels because the excess level of N and P lead to overproduction of autotrophs, which can threaten other aquatic life (Correll, 1998). According to Sahai *et al.*, 1969; Senayya *et al.*, 1979, nitrate concentration depends on the source water and nature of the catchment of a water body. The standard of nitrate concentration for inland surface water is 0.1 mg/l (NEERI, 1988). Denitrification, caused by anaerobic bacteria, is the primary mechanism for nitrogen removal from wetland waters (Sather *et al.,* 1984). Phosphorus can enter wetlands with suspended solids or as dissolved phosphorus. Significant quantities of phosphorus associated with sediments are deposited in wetlands (Walbridge *et al.*, 1993). The standard of phosphate concentration is 0.02 mg/l for surface inland water (Chakrapani *et al.*, 1996). Downing (1992) studied the nitrogen-phosphorus relationships in lakes. Dixit *et al.* (2005) determined the nutrient overloading of a freshwater lake in Bhopal, India. Johnston (2001) for example, stated that the estimated mean retention of phosphorus by wetlands is 45%, and Hammer and Knight (1994) find that natural wetlands could retain 77% nitrate as compared to only 44% by constructed wetlands.

According to Lazrus *et al.* (1970) metal pollution is often primarily anthropogenic in origin, with the greatest concentrations generally being found in areas with heavy industry or mining. Metal concentrations in the water column and the sediments of a water body determine the quality of water (Saikia *et al.*, 1988). Bajpai *et al.* (2002) examined the heavy metal contamination through idol immersion in a tropical lake of Bhopal. Kaverina *et al.* in 2005 made an attempt about the relation between the distribution of Mn and Fe and elements (mostly trace metals) entering the ecosystem of Lake Imandra by anthropogenic discharge. A two years study was undertaken by Singh *et al.* in 2006 to examine the periodic changes in heavy metal loads in waters and sediments of seven natural lakes viz., Bhimtal, Naukuchiatal, Punatal, Sitatal, Rantal, Hanumantal, and Nainital, Uttaranchal, India. Alabaster and Llyod (1982) revealed that zinc is an essential trace element in living organisms and has a cumulative and persistent action.

**B. Biological:**

About 45,000 species of freshwater organisms are known while about one million are yet to be discovered. These organisms constitute about 25% of the total number of organisms. The total number of animal species, reported from, is 89,461; out of which 17,853 belong to wetlands comprising 19.9% of the total number (Kulshrestha, 2005). Deepa *et al.* (1991) estimated that freshwater wetlands alone support 20 % of the known range of biodiversity in India. Mitchell *et al.* (1990) recorded that wetlands in India support 2400 species and subspecies of birds. But losses in habitat have threatened the diversity of these ecosystems. Kumar *et al.,* 2003 find that 242 of the Indian birds are wetland dependent. Gopal (1985) recorded that total number of aquatic plant species exceeds 1200. Green *et al.*, 2002 opined that nutrient

enrichment may adversely impact plant species richness in wetlands and enhance their susceptibility to colonization and dominance by invasive species.

Duarte *et al.* (1986) found that the slope of the littoral zone could explain 72% of the observed variability in the growth of submerged plants. Gentle slopes support more plant growth than steep slopes (Engel, 1985). On the other hand restored wetlands often fail to resemble extant wetlands in vegetative structure and composition, and in plant and animal diversity (Mack 1985; Delphey *et al.,* 1993; Reinartz *et al.,* 1993; Galatowitsch *et al.,* 1996 a, b). Cooke *et al.* (1993) noted that increased phosphorus levels in the water column are not only directly linked to nuisance growths of aquatic weeds. *Phalaris arundinacea L.* (reed canary grass), a cool season, perennial grass, believed to be indigenous to the North American Continent but improved by selection (Galatowitsch, Anderson *et al.,* 1999). Community structure change is an ecosystemic resilience response to a change in the lake nutrient environment (Quiros, 2000).

Macrophytes are considered as important component of the aquatic ecosystem not only as food source for aquatic invertebrates, but also act as an efficient accumulator of heavy metals (Devlin, 1967; Chung *et al.*, 1974). Denny (1987) recognized the following categories; emergent, surface floating, rooted leaves and submerged macrophytes. Several of the submerged, emergent and free floating aquatic macrophytes are known to accumulate and bioconcentrate heavy metals (Bryan, 1971; Chow *et al.*, 1976). Many of the aquatic macrophytes are found to be the potential scavengers of heavy metals from water and wetlands (Gulati *et al.*, 1979). Brix et al., 1989 and Ellis *et al.*, 1994, explained aquatic plants as biological filters of polluted waters.

Brix *et al.,* 1989; Dunbabin *et al.,* 1992 and Ellis *et al.* 1994 described various examples where wetlands-utilizing aquatic plants are employed for removal of

pollutants, including metals, from waters. Aquatic plants are known to accumulate metals from their environment (Outridge *et al.,* 1991) and affect metal fluxes through those ecosystems (Jackson *et al.,* 1994; St-Cyr *et al.*, 1994). Wetland plants remove small quantities of nutrients, trace metals, and other compounds from the soil water and incorporate them into plant tissue, which may later be recycled in the wetland through decomposition, stored as peat, or transported from the wetland as particulate matter (Boyt and others, 1977; Tilton *et al.*, 1979; Hammer, 1992). Windham and coworkers (2004) found that submerged litter from wetland plants accumulated heavy metals in excess of sediment concentrations.

Individual wetlands have a limited capacity to absorb nutrients and differ in their ability to do so (Tiner, 1985). Odum (1988) opined macrophytes as "nutrient pumps" through their action as they play a prominent role in nutrient and heavy metal recycling of many aquatic systems (Pip *et al.*, 1992). A few studies have correlated aqueous concentrations of metals with other chemical parameters (Turner *et al.*, 1985; Stephenson *et al.*, 1988; Watras *et al.*, 1998). For instance, aqueous Hg has been related to dissolved organic carbon (DOC) and other metals (Watras *et al.*, and aqueous Cd, Pb, and Zn have been related to pH, dissolved oxygen, carbonate, and nutrients (Turner *et al.*, 1985, Stephenson *et al.,* 1988; Prahalad *et al.,* 1989). Due to the abilities of macrophytes to absorb and tolerate heavy metals, several studies of plant metal content in relation to environmental metal concentration have been carried out with aquatic plants as pollution indicators (Pip *et al.*, 1992). According to Dennison *et al.*, 1993, aquatic plants serve as indicators of water quality because of their sensitivity to water quality parameters, such as water clarity and nutrient levels. Westlake *et al.*, 1998, revealed apart from absorbing macronutrients, the macrophytes also absorb many minor elements, which are regard in trace quantities. Chen *et al.* (2000) examined links between watershed

characteristics and aqueous metal levels in lakes. Research has shown that wetland plants create oxygenated microenvironments around their roots and thereby release sulfides from sediments (Azzoni *et al.*, 2001). Bentivegna *et al.* 2004 assessed influence of sediment characteristics on heavy metal toxicity in an urban marsh.

Ellis *et al.* 1994 opined that to improve understanding of the importance and roles of aquatic plants, we must investigate metal uptake and localization. Studies in many natural and created wetlands have found that the majority of wetland plants retain higher amounts of metals in their roots than in shoot tissue (Windom *et al.*, 1976; Breteler *et al.*, 1981; Schierup *et al.*, 1981; Peverly *et al.*, 1995 and Keller *et al.*, 1998). Submerged rooted plants have some potential for the extraction of metals from water as well as sediments, while rootless plants extracted metals rapidly only from water (Cowgill, 1974). Denny (1980 and 1987) further noted that main route of heavy metal uptake in wetland plants was through the roots in the case of emergent and surface-floating plants, while euhydrophytes take up heavy metals through leaves and roots.

According to Suren (1989), cell walls tend to break down more slowly than other components and their breakdown also exposes new binding sites for metals. As a result, cell wall-bound metals may be exported from a wetland to a lesser extent than those metals bound intracellularly. Outridge *et al.* (1991) reported that the concentrations of heavy metals in the root tissues of freshwater macrophytes from polluted areas were usually found to contain higher concentrations of most metals compared to the above ground parts. Vesk *et al.*, 1999 observed metal localization in water hyacinth roots from an urban wetland. There is evidence that wetland plants can accumulate heavy metals in their tissues, such as duckweed (*Lemna minor*) (Zayed *et al.*, 1998), water hyacinth (*Eichhornia crassipes*) (Vesk *et al.*, 1999), salix (Stoltz *et al.*, 2002),

cattail (*Typha latifolia*) and common reed (*Phragmites australis* (Ye *et al.*, 2001). Windham *et al.* (2003) studied uptake and distribution of metals in two dominant salt marsh macrophytes, *Spartina alterniflora* (cordgrass) and *Phragmites australis* (common reed).

Limited mobility of Cu with high retention in roots has been reported by a number of authors (Jarvis *et al.*, 1981; Lepp *et al.,* 1984 and Sela *et al.*, 1988). Root plaques, predominantly of Fe, are commonly found on wetland plants with anchored roots and conflicting results have been reported as to their effects on metal uptake, immobilization and tolerance (Otte *et al.* 1989; St-Cyr *et al.*, 1996 and Ye *et al.,* 1997). Zinc is the only metal exhibiting a relatively clear pattern of increasing accumulation in aquatic macrophytes with increasing sediment concentration (Cardwell *et al.*, 2002).

Salati (1987) reported a study on heavy metal uptake by water hyacinth (*Eichhornia crassipes*) in Brazil. A considerable amount of work has been carried out on different aspects of hydrobiology of the Himalayan lakes (Das *et al.*, 1989; Zutshi *et al.*, 1972; Pant *et al.*, 1985; Zutshi, 1989; Khulbe, 1992; Rawat *et al.*, 1993; Jana, 1998; Jain *et al.*, 1999). Matagi *et al.* (1998) made a review of heavy metal removal mechanisms in wetlands. Osumo (2001) carried out a study on the effects of water hyacinth on water quality of Winam Gulf, Lake Victoria. Some hydrobiological features of Lake Mirik, situated in the Darjeeling Himalayas were studied by Jha *et al.* (2003). Parashar *et al.* (2003) find out the biomagnification of heavy metals in certain dominant macrophytic species of the Upper Lake, Bhopal. Weis *et al.*, 2003, reviewed studies to investigate the effects of plants on metals in wetlands. DNR, 2004, conducted a study of the aquatic macrophytes (plants) in Mission Lake. Deng *et al.* (2004) conducted a study about accumulation of lead, zinc, copper and cadmium by 12 wetland plant species thriving in metal contaminated sites in China. Miretzky *et*

*al.* (2004) assessed the aquatic macrophytes potential for the simultaneous removal of heavy metals at Buenos Aires, Argentina.

Otte *et al.*, 1989, described metal accumulation is of interest for basic research into the physiology and ecology of plant survival in flooded conditions and under elevated metal levels. Langston *et al.*, 1994; Phillips, 1994 and Markert, 1995, revealed that despite much work, there are no clear guidelines for biomonitoring of metals using aquatic plants. The surface layer of roots may be enriched in metals but not be bioavailable; further it may affect uptake of metals (Markert, 1995; St-Cyr *et al.,* 1996). Kumar *et al.* (2006) carried out a biomonitoring based study of selected freshwater macrophytes to assess lake trace element contamination as a case study of Nal Sarovar Bird Sanctuary, Gujarat, India.

## C. Ecological:

Hutchinson (1957) described some 76 types of lakes, simply based on their geomorphic origin. According to Gengerke *et al.*, (1972) the physical-chemical characteristics of ponds and lakes reflect the geological characteristics of their watersheds. Bajpai *et al.*, (1994) carried out an ecological study on a fresh water pond in Gwalior M.P. TSPCB in 2003, made an environmental and ecological assessment of Kalyan Sagar Lake. Babar *et al.* (2007) conducted a study on environmental characteristics of Lonar Lake with reference to geological and microbial attributes.

Watershed influences internal dynamics of an individual lake. Naturally eutrophic lakes are often found in basins dominated by rock rich in soluble nutrients (*e.g.* limestone or apatite; Cahoun, *et al.* 1990). Pandey *et al.* (2001) investigated the effects of catchment characteristics on ecosystem properties of

Baghdara Lake, a tropical fresh water reservoir of Udaipur, India. According to Pandey *et al.* (2001), it is expected that lakes with different catchment characteristics would differ with respect to ecosystem properties. Ramachandra *et al.*, 2001 find out that the components of aquatic ecosystem and their working pattern are highly dependent on the catchment's structure and the land use pattern in the catchment. Wetland sediments are generally considered a sink for metals. Wetzel, 1975, revealed that aquatic sediment plays a critical role in the water quality modeling and nutrient cycling of the aquatic environment. In sediments heavy metals are adsorbed to clay and organic matter by electrostatic attraction (Patrick *et al.*, 1990). Sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow, particulate size, and vegetated area of the wetland (Aust *et al.*, 1991; Johnston 1991; Crance 1988; Hemond *et al.,* 1988). Moorthy *et al.* (2005) examined the sediment characteristics of Madhurantakam Lake, Tamilnadu, India.

Schueler (1994) reviewed 23 studies of stormwater pond sediment chemistry and derived a median phosphorus value of 583 mg/kg and Zn was found in high concentration. In fact, Callender *et al.* (2000) reported that zinc levels in southeastern reservoir sediments were highly correlated with both watershed population density and vehicle miles traveled. Koppen *et al.* (1984) and Schueler (1994) also reported zinc enrichment in the bottom sediments of suburban lakes and stormwater ponds, respectively.

## Restoration and Management and Policy

UNEP, 1994, observed that loss of aquatic ecosystems worldwide occur cumulatively through lack of knowledge or fragmented approach in resource management. Samant (1999) noted that as many as 700 potential wetlands do

not have any data to prioritize. Thus appropriate management and restoration mechanisms need to be implemented in order to regain and protect the physical, chemical and biological integrity of wetland ecosystems. The wetland management program generally involves activities to protect, restore, manipulate, and provide for the functions and values emphasizing both quality and acreage by advocating sustainable usage of them (Walters, 1986). Restoration means re-establishment of pre-disturbed aquatic functions and the related physical, chemical and biological characteristics (Cairns, 1988 and Lewis, 1989).

Milstein, 1992, opined that with wise management, wetlands are undoubted assets to the urban environment. Panini (1998) prepared a case study on "The Ramsar Convention and National Laws and Policies for Wetlands in India". RIDEM, 1999, carried out a study on status and trends of freshwater wetland protection and management in Rhode Island. Ramchandra *et al.* (2002) conducted a study on status of Varthur Lake: opportunities for restoration and sustainable management. Dixon (2003) discussed the impacts of drainage and cultivation on wetland hydrology and draws attention to local wetland management strategies, particularly those characterized by multiple uses of wetlands, where agriculture exists alongside other wetland uses. In 2005, Ramachandra *et al.,* outlined the role of the stakeholders especially public and private sectors in managing the ecosystems in a sustainable manner while evolving the management strategies. Odada *et al.*, 2006 studied the challenges of an ecosystem approach to water monitoring and management of the African Great Lakes.

Different methods and models are available to improve the science of wetland systems (Mitsch *et al.*, 1988; Anderson *et al.*, 1992 and Jorgensen, 1986). Some are focused on a single dimension (i.e. Janse *et al.*, 1992), while system modeling requires a multidisciplinary effort (i.e. Hopkinson *et al.*, 1988 Van

der Valk, 1989; De Swart *et al.*, 1994). To aid and improve wise use and management of wetland resources, economic valuation aids as a powerful tool for measuring and comparing the various benefits of wetlands (Edward *et al.*, 1997).

The present study of Lakshmital which is one of the important lakes of Jhansi city was carried out to identify the most appropriate indicators for ecosystem health for wetland-system components and assessment of socio-economic pressures on the lake ecosystem to develop specific planning and restoration strategy for Lake Lakshmital.

# Description of Study Site

## General

Jhansi is a city of Uttar Pradesh state, India (**Figure 3.1**). Jhansi is a major road and rail junction, and is the administrative seat of a district and division of the same name. The walled city grew up in 1613 around its stone fort, which crowns a neighboring rock. It is of historical importance since very first freedom struggle of India – 1957.

## Geography

The district Jhansi lies between latitude $25^0$ $30^1$ and $25^0$ $57^1$ (North) and longitude $78^0$ $40^1$ and $79^0$ $52^1$ (East) and has an area of 5,024 square kilometers. Jhansi is bounded by Jalaun district in north, Lalitpur and Tikamgarh districts in south, Hamirpur district and river Dhasan in east and Shivpuri and Datia districts in west.

## Physical Features

### Topography:

Jhansi is comparatively level: a low lying and fertile tract. It has the general appearance of a plain dotted with isolated low and rocky hills and comprises the northern part of tehsils Jhansi, Moth, Garautha, and the north eastern part of Mauranipur. Physically the district has two distinct portions namely north-eastern plains and the south-western plateau.

## Geology and Soil:

Jhansi is well known for its unique assemblage of granite rocks known as Bundelkhand-Granitic Complex. Geologically, the northern boundary of Jhansi is partially Gangetic alluvium. Bundelkhand granite and gneiss are in plenty. Like in other parts of Bundelkhand, quartz reefs are visible along the granites and are also adorned with igneous rocks at many places.

Three types of soils are found in the district, of which Mar, which is a dark soil, with moisture retaining power, is fertile and excellent for wheat production. Alluvium soil, known locally as Parwa, is found along some stretches of river bank, is also fertile, but subject to inundation during rainy season. Kabar, which is less fertile soil, becomes sticky during rains, dries and splits, is unsuitable for cultivation.

## Drainage and Water-Resources

The slope of the city is towards north and north-east which is apparent from the direction of the rivers and streams flowing and touching this district. Betwa, Dhasan, Pahuj and Sarpar are the major perennial streams along with their numerous tributaries drain off entire district well. Total number of wetlands in Jhansi district as reported by SAC, ISRO, is 16, covering an area of 5127.47 hectares. Predominant wetland types are man-made lakes and reservoirs/tanks, historically noted among those are Lakshmital, Antiatal and Baruasagar Lake. Two of them lay in the Jhansi city itself i.e. Antiatal and Lakshmital.

# Climate

The average annual rainfall of the district is 880 mm. The district receives 91% of its annual precipitation from the south west monsoon which reaches the district after mid June and withdraws by the end of September, July being the month of heaviest rainfall; on an average there are 42 rainy days in a year.

In Jhansi district, the mean annual maximum and minimum temperatures are 32.8 $^0$C and 17.86 $^0$C respectively. The maximum temperature could be as high as 48 $^0$C and minimum could drop as low as 4$^0$C. From March onwards, both day and night temperatures begin to rise progressively and May is the hottest month of the year. After the withdrawal of monsoon in September, the day temperature begins to rise slightly, but the night temperature decreases progressively.

The air is very dry during the summer season especially in afternoon when the average relative humidity is less than 20%. During the monsoon season the moisture content of the air is high. The average relative humidity in the post monsoon and winter months is generally between 50%-65% in the mornings and 25%-40% in the afternoons.

Knowledge of meteorological characteristics in the study area is necessary as transport and diffusion of the pollutants in the atmosphere is determined by meteorological factors. Wind speed, wind direction and atmosphere stability are basic meteorological parameters because the dispersion and dilution of the pollutants depends mainly on these, whereas secondary meteorological parameters like temperature, humidity, precipitation, solar radiation, pressure and visibility etc. control the dispersion of pollutants indirectly by affecting primary parameters.

## Lakshmital

Lakshmital is a beautiful lake outside the city wall in the direction of Kaimasan Hill. It is surrounded by little hillock and around the tal, there are twelve temples built in similar design. Adjoining the Lakshmital, there is Narayan Bagh, the famous garden of Jhansi (**Figure 3.2**).

Lakshmital covers an area of 32.52 hectares with an average depth of 2.5 meter. It lies between longitude of $78^0\ 37^1$ E and $25^0\ 57^1$ N of latitude. Lakshmital has a catchment area of 2370 hectares having a storm water intensity of nearly 0.75 per hour/acre of flood rain. It is a rain fed water body.

Like many other water bodies in India Lakshmital is also under ecological crisis due to various urban anthropogenic activities:

*1. Sewage disposal:* The taal is getting polluted through nalas which carry huge quantity of commercial and domestic waste and discharge it into the taal. Six nalas discharge their sludge from 19 localities into the taal. Along with this discharges from Kasai Mandi run to lake. Incineration waste and remain from marghata are also thrown into the taal.

*2. Surface runoff:* There is no boundary wall or grit chamber around the lake thus in rainy season all waste along with surface runoff from road side and other areas come into the lake.

*3. Bathing Ghats:* From the fort of the east bank of Lakshmital we can see the bathing ghats and the embankment which are massively and artificially built. A proposed dhobi ghat is also present in the nearby area responsible for deteriorating the water quality of the taal.

4. *Open toilets and solid waste dumping:* Nearby community of Lakshmital do not have adequate sanitation facilities. Due to the reason some of them use peripheral region of taal for waste dumping and for toilet purposes that also exacerbates the condition of lakshmital by giving birth to insects, fowl odour and pathogenic pollution in taal.

5. *Eutrophication:* Due to continuous organic matter flow within sewage water, the BOD of taal has crossed its permissible limits. The major part of lake has become eutrophic and remaining less part is mesotrophic.

Apart from these activities, a number of other natural processes like decomposition of dead leaves and other plant remains, siltations etc., also cause degradation in lake quality. All these anthropogenic activities are contributing to a greater extent of organic matter loading the water body.

## Sampling sites

Eight sampling sites were selected after a preliminary survey to carry out the present study. These sites have been named as site I, II, III, IV, V, VI, VII, and VIII. According to Ismail *et al.* (2005) the water chemistry of wetlands is primarily a result of the geologic setting, water balance. Therefore, these sampling sites have been chosen on the basis of relative proportion of inflow, outflow and storage, quality of inflowing water, types of soils and vegetation, and human activities within or near the wetland. Details of selected sampling sites are shown in **Figure 3.3** that is as follows:

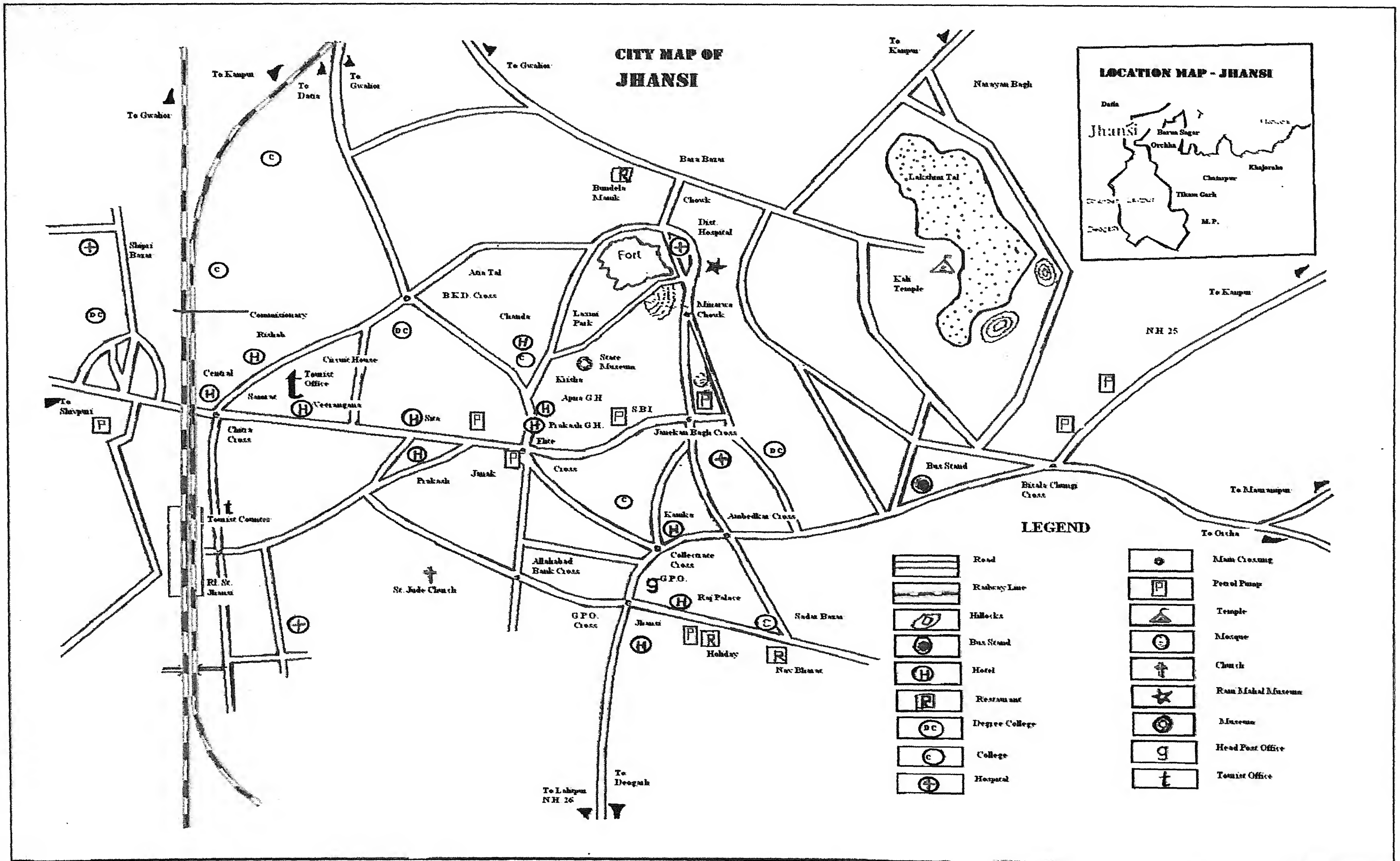



**Figure 3.1. City map of Jhansi**

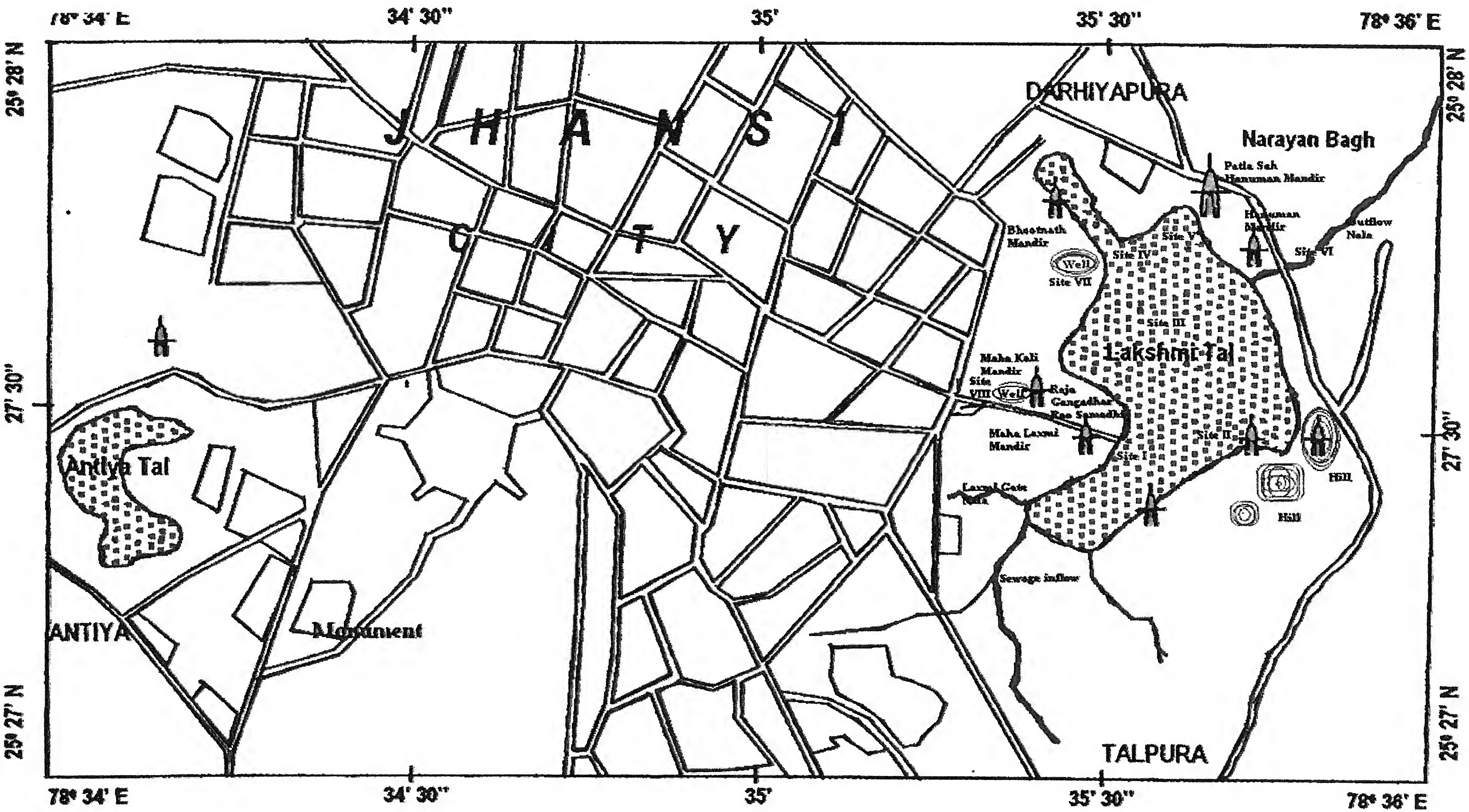
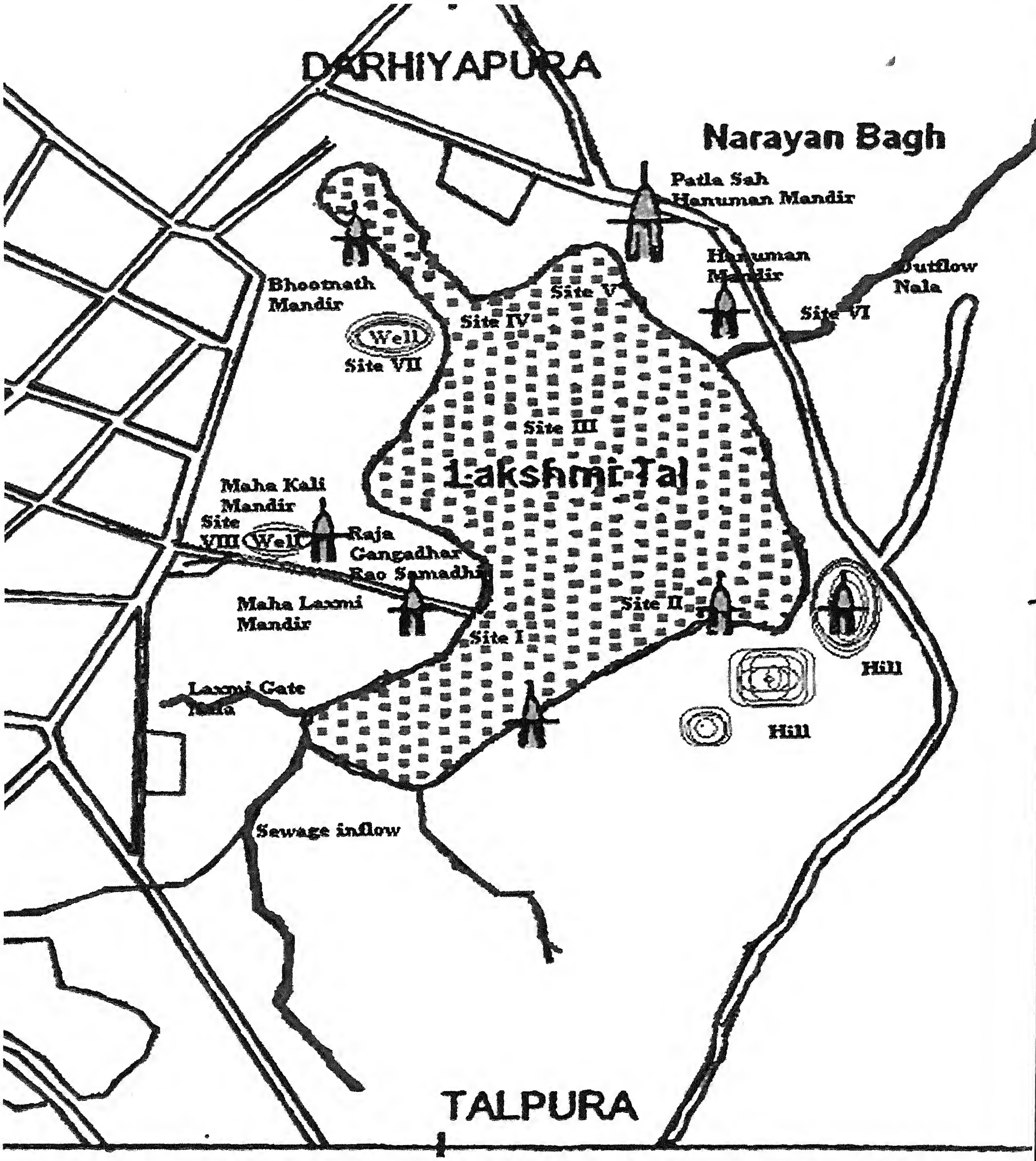



**Figure 3.2. Map showing the study area**




| Sampling Sites | |
|---|---|
| 1. Inflow of sewage | 2. Watershed region |
| 3. Central lake | 4. Area adjacent to boundary wall |
| 5. Area near farms | 6. Outflow to Narayan Bagh |
| 7. Well water near Bhutnath temple | 8. Well water near Kali temple |

**Figure. 3.3. Map showing the sampling sites in Lakshmital**

**Plate 3.1. Inflow of sewage, showing sampling Site I**

**Plate 3.2. Watershed region, showing sampling Site II**

**Plate 3.3. Central lake region, showing sampling Site III**

**Plate 3.4. Lake area adjacent to boundary wall, showing sampling Site IV**

**Plate 3.5. Area adjacent to farms, showing sampling Site V**

**Plate 3.6. Outflow to Narayan Bagh, showing sampling Site VI**

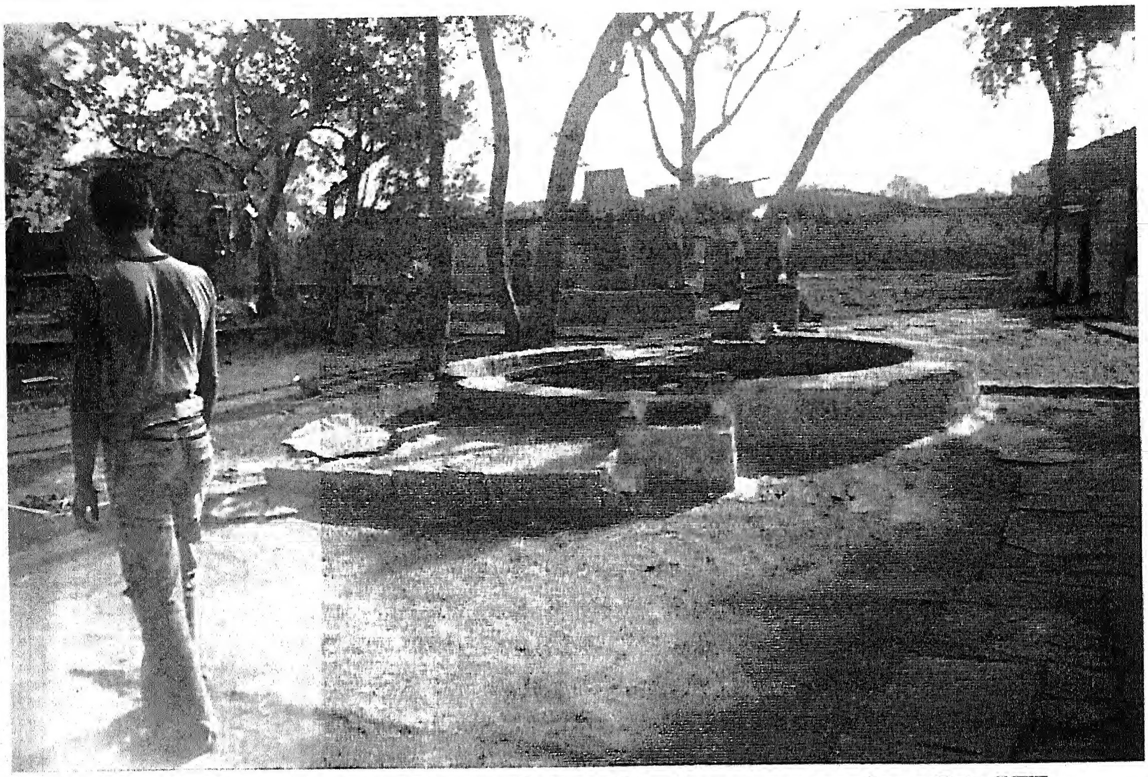


**Plate 3.7. Well water near Bhutnath temple, showing sampling Site VII**

**Plate 3.8. Well water near Kali temple, showing sampling Site VIII**

# Material and Methods

## Sampling

Water samples from Lakshmital were collected in three different seasons viz., winter, pre-monsoon and post-monsoon during the period of one year from May 2006 to February 2007. Sampling was done in three days randomly from each of the sites.

On the basis of inflow, outflow, and human activity six stations were selected for sampling. Samples were collected from 10-30 cm. below the surface of the water during morning hours. These samples were collected in thoroughly cleaned and rinsed (3-4 times) plastic bottles and tightly capped immediately after collection, except samples collected for DO determination. To determine DO, the samples were collected in BOD bottles (300 ml.) in which manganous sulphate and potassium iodide were added instantaneously after the collection. Similarly two samples were collected from wells located in periphery of the lake.

*Sediment sampling* was carried out from one location during a period of five days randomly. The sample was collected in clean polythene.

All the samples were labeled on the sample container clearly denoting the number, location of body of water, date and time of sampling and transported to the laboratory for analysis.

*Macrophytes sampling:* Macrophytes were hand picked from the lake, transported to the laboratory and stored species-wise following standard taxonomic manuals.

## Analysis

A detailed analysis of collected samples was carried out under following categories: (A) physico-chemical analysis; (B) biological analysis; (C) soico-economic analysis; (D) statistical analysis.

### (A) Physico-chemical Analysis

A physical and chemical characteristic of water is required to assess and determine the quality to ascertain their suitability for various purposes. In the present study physico-chemical analysis of water samples was done as per the procedures described in Standard Methods for the Examination of Water and Waste Water (APHA, 1998).

**Determination of Temperature:**

*Principle:* Temperature is an important factor for its effects on chemical and biological reactions in water. A rise in temperature of water accelerates chemical reactions, reduces solubility of gases, amplifies taste and odour, and elevates metabolic activity of organisms.

*Materials required:* A mercury thermometer.

*Procedure:* Took water in a plastic container and recorded its temperature immediately by dipping the thermometer for about one minute.

**Determination of pH:**

*Principle:* The pH is determined by measurement of the electromotive force (emf) of a cell comprising an indicator electrode, an electrode responsive to hydrogen ions (Glass electrode) immersed in the test solution, and the reference electrode is achieved by means of a liquid junction in the reference electrode.

*Materials required:* pH meter, glass electrode, reference electrode.

*Procedure:*

(i) Rinsed the electrodes with distilled water and dried with gentle wiping with a soft tissue paper.

(ii) Standardized the instrument with the electrode immersed in a buffer solution with the pH close to that of the water to be tested.

(iii) Set the manual temperature compensation to the temperature of the buffer.

(iv) Checked the electrode response by measuring a second buffer solution of different pH.

(v) Rinsed with distilled water and wipe with tissue paper after every measurement. The difference in reading for the standard did not exceed 0.1.

(vi) Immersed the electrode in the sample taking final reading after 30 seconds.

**Determination of Turbidity:**

*Principle:* This method is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same condition.

*Materials required:* Nephlometer, sample tube and stock turbidity suspension.

*Procedure:*

(i) Set the instrument zero with distilled water.

(ii) Filled the standard 40 NTU suspension in test tube and put into the sample holder, set the display 40 NTU.

(iii) Put the sample in the sample holder and read the display.

**Determination of Conductivity:**

*Principle:* Conductance when measure between the electrodes having a surface area of 1cm square and placed at a distance of 1cm is called electrical conductivity and is the property of the water samples rather than measuring system.

*Materials required:* Conductivity meter and standard KCl 0.01M.

*Procedure:* Calibrated the instrument with standard 0.01M KCl solution (1413 umho/cm). Dipped the electrode in original sample and measure the conductance.

**Determination of Total Solids:**

*Principle:* Total solids (TS) are determined as the residue left after evaporation of the unfiltered sample.

*Materials required:* Evaporating dishes, Muffle furnace for operation at 500± $50^0$C, Steam bath, Desiccator, Analytical balance, and Whatman filter paper (44u).

*Procedure:* 50 ml of unfiltered sample was taken in completely dried and pre weighted ($W_1$) evaporating dishes and kept on boiling water bath at $98^0$C in an oven for an hour. Final weight ($W_2$) of the dishes after cooling them in dessicator was noted. The total solid contents in mg/l were calculated by the following formula:

$$\text{Total Solids (mg/l)} = [(W_2 - W_1) \times 1000/ (\text{ml of sample})]$$

Where,

$W_1$ = Initial weight of the dish (mg)

$W_2$= Final weight of the dish (mg)

**Determination of Total Suspended Solids:**

*Principle:* Total dissolved solids (TSS) are determined as the residue left after evaporation of the filtered sample.

*Procedure:* 50 ml of sample was taken and filtered through a suitable tared gooch crucible ignited to constant weight ($W_1$), washed the residue three times with about 5 to 10 ml of water allowing it to drain free from water after each wash. Carefully removed the crucible and dried in an oven at $105^0$C for one hour. Cooled in a desiccator and weighted ($W_2$). Total suspended solids were calculated as follows:

$$\text{Total Suspended Solids (mg/l)} = [(W_2 - W_1) \times 100/ (\text{ml of sample})]$$

**Determination of Total Dissolved Solids:**

The total dissolved solids (TDS) were determined as the difference between the total solids and were expressed in mg/l by the relation:

$$\text{Total Suspended Solids (mg/l)} = \text{T.S.} - \text{T.S.S.}$$

**Determination of Total Hardness:**

*Principle:* EDTA (Ethylene diamine tetra acetic acid) and it's sodium salt forms a chelate complex when added to a solution of certain metal cations. At pH 10±0.1, EDTA preferably forms complex with calcium and magnesium. If, a

small amount of dye such as Eriochrome Black T (EBT) or calmagite is added to an aquous solution containing calcium and magnesium at pH 10±0.1 the solution becomes wine red because the metals form an unstable complex with dyes. If, EDTA is added as titrant, the calcium and magnesium will be chelated with EDTA to form EDTA – metal complex, which is more stable. When all the magnesium and calcium has been complexed, the solution turns blue as the indicator will be free from metal-indicator unstable complex marking the end point of titration. Magnesium ion must be present in solution to yield a satisfactory end point. To ensure it, a small amount of compleximetrically neutral magnesium salt of EDTA is added to the buffer, this automatically introduces sufficient magnesium and obviates the need to blank correction. The sharpness of the end point increases with increasing pH. However, the pH cannot be increased indefinitely because of the danger of precipitating calcium carbonate ($CaCO_3$) or magnesium hydroxide [$Mg(OH)_2$]. So, pH at 10.0±0.10 is a satisfactory compromise.

*Materials required:* Ammonia Buffer Solution, Standard EDTA 0.01 (M), Standard Calcium Solution, Eriochrome Black – T (EBT).

*Procedure:* 50 ml of sample was taken in a conical flask and in it 1-2 ml. of ammonia buffer solution was added followed by 1 ml. in inhibitor. Added a pinch of Eriochrome black -T indicator and the solution was titrated with standard EDTA (0.01m) till wine red colour changes to blue. The volume of EDTA required was noted and total hardness was calculated by the relation:

Total Hardness (mg/l) = [(ml of titrant used x 1000) / (ml of sample)]

**Determination of Total Alkalinity:**

*Principle:* Alkalinity of a sample can be estimated by titrating with standard sulfuric acid. Titration to pH 8.3 or decolourisation of phenolphthalein indicator

which indicate complete neutralization of pH and ½ of $CO_3^-$ while to ph 4.5 or sharp change from yellow to pink of methyl orange indicator will indicate total alkalinity.

*Materials required:* Standard $H_2SO_4$ (0.02N), Phenolphthalein indicator and Bromcresol Green indicator.

*Procedure:* 50 ml of sample was taken in a conical flask. To this 2-3 drops of phenolphthalein indicator was added. If the pink colour develops, the sample was titrated with 0.02N sulphuric acid titrant till the disappearance of pink colour. The volume of titrant used was recorded (P) and phenolphthalein alkalinity was calculated by using equation -1.

To this sample 2-3 drops of methyl orange indicator were added and was titrated using 0.02N sulphuric acid titrant and on the end point the yellow colour change to orange. The volume of titrant used was recorded (M) and the methyl orange alkalinity was calculated by using equation-2. By adding both the values (P+M), total alkalinity of the water was obtained by (equation -3).

$$\text{Phenolphthalein Alkalinity (mg/l) as } CaCO_3 = [(P \times 1000)/ (\text{ml of sample})] \quad \ldots\ldots\ldots\ldots (1)$$

$$\text{Methyl Orange Alkalinity (mg/l) as } CaCO_3 = [(M \times 1000) / (\text{ml of sample})] \quad \ldots\ldots\ldots\ldots (2)$$

$$\text{Total Alkalinity (mg/l) as } CaCO_3 = [(P+M) \times 1000 / (\text{ml of Sample})] \quad \ldots\ldots\ldots\ldots (3)$$

**Determination of Chloride:**

*Principle:* In neutral or slightly alkaline solution potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is quantitatively precipitated before red silver chromate is formed.

*Materials required:* Potassium Chromate indicator solution and Standard silver nitrate solution.

*Procedure:* To a conical flask containing 50ml. of sample, 1 ml of potassium chromate indicator was added and the contents were titrated with 0.0141N standard silver nitrate titrant to brick red end point. Chloride contents were calculated in mg/l by the relation:

Chloride (mg/l) = [(ml. of titrant x 0.141 x 35.45 x 1000) / (ml of sample)]

**Determination of Dissolved Oxygen:**

*Principle:* Dissolved oxygen (DO) is allowed to react with I-to from $I_2$ which is then titrated with standard $Na_2S_2O_3$ solution. A fast quantitative reaction is ensured by addition of Mn (II) salts in strongly alkaline medium.

*Materials required:* $MnSO_4.4H_2O$ Solution, Alkaline-iodide reagent, Conc. $H_2SO_4$, Starch and Standard 0.025N Sodium thiosulphate.

*Procedure:*

(i) D O was determined by Winkler's method.

(ii) Taking a stoppered glass BOD bottle of known volume and filled it with the sample avoiding any bubbling. No air should be trapped in bottle and poured in it 2 ml. of each $MnSO_4$ and alkali-iodide-azide reagent using separate pipettes.

(iii) Precipitate would appear placed the stopper and shake the bottle thoroughly.

(iv) Added 2 ml of conc. $H_2SO_4$, shake thoroughly to dissolve precipitate.

(v) Transferred sample gently in a conical flask. Added a few drops of starch indicator. Titrated against $Na_2S_2O_3$ (0.025N) solution and noted the end point when initial blue colour turned colourless.

*Calculation:*

Dissolved Oxygen (mg/l) = [(N x V x 8 X 1000) / (ml. of sample)]

Where,

N = Normality of sodium thio-sulphate

V = Volume of Sodium thio-sulphate used

**Determination of Bio-Chemical Oxygen Demand:**

*Principle:* The principle of method of biological oxygen demand (BOD) determination, involved, measuring the difference of the oxygen concentration between the sample and after incubating it for 5 days at $20^0$C.

*Materials required:* BOD bottles (glass-stoppered bottles), BOD incubator, Phosphate buffer, Magnesium sulphate solution, Calcium chloride solution, Ferric chloride solution.

*Procedure:*

(i) Bubbled compressed air in distilled water for 30 minutes-this water is then called dilution dilution water.

(ii) In a litre of dilution water added 1c.c. each of phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solution and mixed well.

(iii) Neutralized the water sample pH 7.

(iv) In conditions, the dissolved oxygen of the sample might not be sufficient for the oxidation of biologically degradable organic matter so that the sample was mixed with a known volume of dilution water which was rich in oxygen.

(v) Filled two sets I and II of BOD bottles.

(vi) Determined the dissolved oxygen in the sample bottles of set I immediately.

(vii) Determined the dissolved oxygen in the sample bottles of set II after keeping the bottles in a BOD incubator at $27^0$C for three days.

*Calculations:*

$$BOD\ (mg/l) = (D_0 - D_3) \times \text{Dilution Factor}$$

Where,

$D_0$ = Initial dissolved oxygen in the sample.

$D_3$ = Dissolved oxygen left out in the sample after 3 days of incubation.

**Determination of Chemical Oxygen Demand:**

*Principle:* A sample is refluxed in strongly acid solution with a known excess of potassium dichromate after digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed.

*Materials required:* 0.25 N $K_2Cr_2O_7$, 0.1 N Ferrous ammonium sulphate, Ferroin indicator solution, Concentrated $H_2SO_4$, Solid $HgSO_4$ and $Ag_2SO_4$.

*Procedure:*

(i) Took 20 ml of sample in the reflux unit and added 10 ml of $K_2Cr_2O_7$ solution, a pinch of silver sulphate and 30 ml of $H_2SO_4$.

(ii) Attached Liebig condenser to the mouth of flask and heated the flask on a hot water bath for atleast 2 hours to reflux the contents.

(iii) Cooled the flask, detached from the unit and diluted its contents to about 150 ml by adding the distilled water.

(iv) Added 2 drops of ferroin indicator solution and titrated against ferrous ammonium sulphate solution (0.1N).

(v) At the end point blue green colour of the contents changed to wine red.

(vi) Refluxed blank in the same manner using distilled water instead of sample.

*Calculations:*

$$COD\ (mg/l) = [(A-B) \times N \times 8000 / (ml\ of\ sample)]$$

Where,

A = Volume of titrant used against sample.

B = Volume of titrant used against blank.

N = Normality of titrant.

**Determination of Phosphate:**

*Principle:* Molybdophosphoric acid is formed and reduced by stannous chloride to intensely coloured molybdenum blue.

*Materials required:* Spectrophotometer for use at 690 nm., Ammonium molybdate, Stannous chloride

*Procedure:* Phosphate was determined by stannous chloride method. Phosphate in water sample was estimated by stannous chloride method. 100 ml of sample was taken in a test tube and two drops of phenolphthalein indicator was added. If pink colour appeared it was discharged by strong acid solution. 4 ml. of ammonium molybdate and 0.5 ml. of stannous chloride reagent were added to the sample with thorough mixing after each addition. The blue colour of solution appeared between 10-12 minutes at 690 nm. with the help of spectrophotometer. By similar process blanks were prepared. Phosphate in mg/l was calculated by the relation:

$$Phosphate\ (mg/l) = mg\ PO_4\ (from\ curve) \times 20$$

**Determination of Nitrate:**

*Principle:* Nitrate reacts with brucine sulphonilic acid and produces a nitro-derivative which is alkaline solution develops yellow colour due to rearrangement of its structure.

*Materials required:* Spectrophotometer to use at 410nm, Water bath, Brucine sulphonilic acid solution, NaCl solution, sulphuric acid,

*Procedure:* Nitrate was determined by brucine sulphonilic acid method. To a 10 ml. sample in a Nesseler's tube 2 ml. of NaCl solution was added. The tube rack was placed in cool water bath. Contents were mixed and 10 ml. of sulphuric acid solution was also added and contents were cooled in water bath. 0.5 ml of brucine sulfanilic acid solution was added and mixed thoroughly. The tubes rack was placed in boiling water bath at $95^0$C. After 20 minutes, the rack was cooled to room temperature and reading obtained on 410 nm. with the help of spectrophotometer. The values of $NO_3$-N were obtained directly from the standard curve. Nitrate contents in mg/l were obtained by the following relation:

$$\text{Nitrate-N (mg/l)} = [(\text{mg Nitrate-N} \times 1000) / (\text{mg of sample})]$$

$$NO_3 \text{ (mg/l)} = (\text{mg/l Nitrate-N} \times 4.43)$$

**Determination of Sulphate:**

*Principle:* Sulphate is precipitated in an acedic medium with $BaCl_2$ as to form barium sulphate ($BaSO_4$) crystals of uniform size. Light absorbance of $BaSO_4$ suspension is measured by spectrophotometer and $SO_4^-$ concentration is determined by comparison of the reading with a standard curve, in similar fashion.

*Materials required:* Spectrophotometer to use at 420 nm., Magnetic stirrer, Standard sulphate solution, Barium chloride crystals (20-30 mesh).

*Procedure:* Sulphate was determined by turbidimetric method. To a 100 ml. sample in a conical flask 5 ml. of conditioning reagent was added and sulphate was determined by turbidimetric method. The contents were mixed on magnetic stirrer and 1 spoonful of barium chloride crystals were added and stirred for exactly one minute. Immediately after stirring the solution was taken in cuvettes and read at 420 nm. with the help of spectrophotometer. At the maximum reading noted during this period indicated turbidity of barium sulfate. Original sample was used as a blank. Concentration of sulphate was obtained from the standard curve ad calculated in mg/l by the following relation:

$$\text{Sulphate (mg/l)} = [\text{mg } SO_4 \text{ (from curve)} \times 1000 / (\text{ml of sample})]$$

**Determination of Calcium:**

*Principle:* When EDTA (Ethylene diamine tetra acetic acid) is added to water containing both calcium and magnesium, it combines first with the calcium when the pH of the test solution is sufficiently high (12 to 13), magnesium gets precipitated as magnesium hydroxide. Therefore, at a pH of 12 to 13, calcium can b directly estimated by titration with EDTA using a suitable indicator which can only combine with calcium (Murexide or Eriochrome blue black R).

*Materials required:* Standard EDTA solution (0.01M), Sodium hydroxide NaOH (1N), Eriochrome Blue Black RC indicator, Standard calcium solution.

*Procedure:*

(i) Calcium was determined by EDTA and permanganate titration method.

(ii) Took 50 ml sample or a portion diluted to 60 ml.

(iii) In case, the alkalinity of the sample was more than 300 mg/l, neutralized it with acid boiling for 1 minute and cooling it, and then titrated.

(iv) Added 2 ml NaOH (1N) solution or a volume sufficient to produce pH12-13, checked the pH rapidly with paper strip.

(v) Added 0.1 to 0.2g of Eriochrome Blue Black RC indicator.

(vi) Titrated with standards EDTA slowly, with continuous stirring to the proper end point. Completed the titration within 5 minutes.

(vii) Standardized EDTA with standard $CaCO_3$ solution.

Determination of strength of EDTA

10 ml $CaCO_3$ solution is equivalent is 10mg $CaCO_3$

'V' is the volume of EDTA consumed to titrate 10 ml $CaCO_3$

$$\text{Hence, mg equivalent of } CaCO_3 \text{ per ml of EDTA is} = \frac{10\text{mg}}{V\text{ ml}}\ N\text{ mg/ml}$$

$$\text{Calcium as } CaCO_3\ (\text{mg/l}) = \frac{(S\text{-}B) \times (N) \times 1000}{\text{Volume of sample taken for titration}}$$

Where,

S = ml volume of EDTA consumed for sample

B = ml EDTA consumed for blank

N = mg Equivalent of $CaCO_3$ per ml of EDTA

**Determination of Magnesium:**

*Principle:* While measuring total hardness, calcium and magnesium ions react with EDTA to form soluble complexes and completion of reaction is indicated by the colour change of a suitable indicator. By substracting the value of calcium hardness from total hardness, magnesium hardness can be measured. Magnesium as $Mg^{++}$ can be calculated by multiplying magnesium hardness with 0.243.

*Procedure:*

Magnesium as equivalent $CaCO_3$ was estimated by calculating the difference between total hardness and calcium hardness as $CaCO_3$:

Magnesium as mg/l =

(Total Hardness as mg $CaCO_3$/l - Calcium Hardness as mg $CaCO_3$/l x 0.243

**Determination of Fluoride:**

*Principle:* The SPANDS method is based on the reaction between fluoride and a zirconium dye that form a complex anion ($ZrF_6^{-2}$) and dye.

*Materials required:* Spectrophotometer for use at 570 nm., Standard fluoride solution, SPANDS solution, Zirconyl acid reagent and Reference reagent.

*Procedure:*

(i) Fluoride was estimated by SPANDS method.

(ii) Took 50 ml sample in 100 ml beaker.

(iii) Added 5 ml of each SPANDS solution and Zirconyl acid reagent, mixed well and read absorbance at 570nm first setting the Zero absorbance with reference solution.

(iv) Standard solution was run in the same manner in 0-50 μg range, space standards at 10 μg increment.

$$\text{Fluoride (mg/l)} = \frac{\mu g\ \text{F (determined from standard curve)}}{\text{Volume of sample}}$$

**Determination of Sodium:**

*Principle:* A characteristic light is produced due to extraction of electrons when the sample with sodium is sprayed into a flame. The intensity of the characteristic radiation is proportional to the concentration of sodium and can be read at 589 nm by using suitable filter devices. The standard curve is a linear one at the lower concentration of sodium. However, at higher concentrations it has got a tendency to level off.

Potassium and calcium may interfere with the determination of sodium if former is more than 5 times in ratio to sodium; and the latter 10 times. Magnesium will interfere only when its ratio to sodium increase much higher than 100 which is a rare occurrence.

*Materials required:* Flame photometer, Stock sodium solution (1000 mg/l Na); Nitric acid; Hydrochloric acid; Hydrogen peroxide; Ammonium hydroxide.

*Procedure:*

(i) Sodium was determined by flame photometric method.

(ii) Filtered the sample through a filter paper to remove any suspended matter which otherwise might clog the capillary of the instrument.

(iii) Find out the concentration of sodium using flame photometer.

(iv) Prepared a calibration curve in the range of 0 to 1 mg/l of sodium by using standard solution of sodium, used smaller ranges to get accurate results, in case sample with more sodium it was diluted to bring in the of determination.

(v) Used the curve for determination of sodium depending on the initial concentration of sodium in the sample.

**Determination of Potassium:**

*Principle:* Like sodium, potassium can also be determined accurately by flame photometer. The characteristic radiation for potassium is 768nm, the intensity of which can be this wavelength.

*Materials required:* Flame Photometer, Stock potassium solution (1000mg/1K).

*Procedure:* Followed the same procedure as described for determination of sodium except that to use filter for potassium at 768 nm wavelengths instead of sodium filter.

**Determination of Ammonia:**

*Principle:* Ammonia reacts with Nessler's reagent ($K_2HgI_4$) to form a brown coloured substance which can be determined colorimetrically. First, a calibration curve is constructed by using known ammonia solutions and then with the help of this curve the quantity of ammonia in the given water sample is found out.

*Materials required:* Micro Kjeldhal distillation unit and Spectrophotometer for use at 425 nm., Known ammonium chloride solutions, 0.1N $H_2SO_4$, 4% solution of $Na_2B_4O_7.10H_2O$ (buffer solution), Nessler's reagent ($K_2HgI_4$) (all the solutions should be prepared in ammonia free distilled water).

*Procedure:*

(i) Ammonia was estimated using colorimetric method.

(ii) Took 50 ml of the water sample, added 1 ml of borax buffer and passed steam through it.

(iii) Collected the distillate in about 10 ml of 0.1 N sulphuric acid for about 40 minutes when the ammonia, distilled out, forms ammonium sulphate.

(iv) Made up the volume of the distillate to 50 ml and 1 ml of Nessler's reagent, a brown colour developed. Measured the absorbance at 425 nm by means of a spectrophotometer.

(v) Prepared a calibration curve using known solutions of $NH_4Cl$ and find out the concentration of ammonia in the sample with the help of this curve.

**Determination of Iron:**

*Principle:* Sample is treated with hydroxylamine in presence of HCl when the iron present is reduced to the ferrous state. The ferrous iron so produced is treated with an excess of 1, 10-phenanthroline when a red colour is developed whose absorbance can be measured at 510 nm. A calibration curve is prepared using known solutions of ferrous iron and with the help of this curve the amount of iron in the water sample can be found out.

*Materials required:* Spectrophotometer for use at 510 nm., Concentrated hydrochloric acid, Hydroxylamine hydrochloride solution, Ammonium acetate buffer solution, Phenonthroline solution and Standard iron solutions.

*Procedure:* Took 50 ml of a sample and added 2 ml of hydrochloric acid and 1 ml of hydroxylamine hydrochloride solution. Boiled till the contents were reduced to about half the original volume. Cooled and added 10 ml of ammonium acetate buffer solution and 2 ml of phenonthroline solution. Added distilled water to make the volume 100 ml. kept stand for 10 minutes and then recorded the absorbance on spectrophotometer at 510 nm using distilled water as blank.

Processed the standard iron solutions of different concentrations in similar way and recorded the absorbance for each. Plotted a standard curve from these

values and deduced the total iron content of the sample in mg/l by comparing the absorbance for sample with standard curve.

**Determination of Metals (Cadmium, Chromium, Copper, Manganese, Nickel, Lead and Zinc) in water:**

*Principle:* In atomic absorption spectrometry a light beam is directed through the flame, into a monochromator, and on to a detector that measures the amount of light absorbed by atomized element in the flame. The amount of energy at the characteristic wave length absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range.

*Materials required:* Atomic Absorption Spectrometer (AAS), Perchloric acid ($HClO_4$), Nitric acid ($HNO_3$) concentrated, Standard stock solutions.

*Procedure:*

(i) Metals were analysed using AAS method.

(ii) Mixed sample and transferred a suitable volume into a flask or beaker.

(iii) Added 5 ml concentrated $HNO_3$ and few boiling chips and evaporated on a hot plate to 15-20 ml.

(iv) Added 10 ml each of concentrated $HNO_3$ and $HClO_4$ cooling flask between additions.

(v) Evaporated on a hot plate until dense white fumes appear.

(vi) Added 10 ml of concentrated $HNO_3$ on requirement to complete digestion.

(vii) Cooled, diluted to about 50 ml with water and boiled to expel chlorine and filtered.

(viii) Transferred filtrate to 100 ml of volumetric flask with two 5ml portions of distilled water adding these and rinsing to the volumetric flask.

(ix) The above digested sample was aspirated to AAS and concentration of metals was read out.

(x) Operation of AAS: In typical practice, the meter of the readout device is adjusted to zero absorbance or 100% transmittance when a blank solution is sprayed into the flame and the unobstructed light of the hollow cathode lamp passes on the photo multiplier tube. When a solution containing the absorbing species is introduced, a part of the light is absorbed resulting in the increase of the light falling on photo multiplier and producing the deflection.

*Standardization:* Selected three concentrations of each standard metal solution, to bracket the expected concentration of a sample. Aspirated blank and zero the instrument, then aspirated each standard in turn into flame and recorded absorbance. Calibration curve was prepared by the automatic instrument calibration system.

*Analysis of sample:* Rinsed nebulizer by aspirating water containing 105 ml concentrated nitric acid/litre. Aspirated blank and zero the instrument. Aspirated sample and determined its absorbance.

*Calculation:* Read concentration of the desired element directly from the instrument read out; if the sample has been diluted multiply by the appropriate dilution factor.
(Wavelength for cadmium, chromium, copper, manganese, nickel, lead and zinc are 228.8 nm, 357.9 nm, 324.7 nm, 279.5 nm, 232.0 nm, 283.3 nm and 213.9 nm respectively).

**Determination of Metals (Cadmium, Chromium, Copper, Manganese, Nickel, Lead and Zinc) in Sediments:**

*Principle:* (same as described in metals analysis in water)

*Materials required:* Atomic Absorption Spectrometer, pestle and motor and sieve, nitric acid, perchloric acid, hot plate and Whatman filter No-41.

*Procedure:*

(i) Sample of 20g was kept in oven at a temperature of $105^0C$ for 24 hours for moisture removal and was ground using pestle and motor.

(ii) After sieving the sample 10g of sample is accurately weighed and add 1:1 (50% nitric acid + 5% distilled water) 20 ml of nitric acid and 5 ml of perchloric acid. Digestion was done at a temperature of $80^0C$ in hot plate.

(iii) The sample was heated upto dryness and after adding 10 ml of distilled water, filtered through Whatman filter No-41.and finally made up the volume upto 100 ml.

(iv) Rest of the method followed as mentioned in metal analysis in water.

**Determination of Metals (Cadmium, Chromium, Copper, Manganese, Nickel, Lead and Zinc) in macrophytes:**

Individual species were washed carefully. Separated the plants into two parts root and shoot and washed in distilled water. After the process dried at $75^0C$ in hot air oven for 48 hours. Dried samples were homogenized and ground to yield fine powder.

(Rest of the method followed as mentioned in metal analysis in water)

## (B) Biological Analysis

A detailed survey of vegetation of Lakshmital was carried out to collect all the aquatic plant species present in the lake. Plants were hand picked from the lake, transported to the laboratory and stored species-wise following standard taxonomic manuals. Afterwards details of every plant were collected containing

information regarding their classification, habitat, ecological, and socio-economic importance etc., and the collected information was then interpreted and summarized in a form of table.

### (C) Socio-economic survey

A detailed random socio-economic survey of 200 households, situated in nearby localities of the lake namely; Radha Govind Ki Bagia, Narayan Bagh colony, Lakshmi Gate Bahar, Lakshmi Gate Bhitar and Dariya Pura was carried out by using a standard questionnaire (**Appendix-A**). This survey was done during the year of 2006. Questions were presented to the individuals orally and information gathered was recorded onto a survey form. Besides interviews some personal discussions were also carried out with the individuals residing in the fringes of the lake Lakshmital.

The questionnaire was planned to access data regarding socio-economic study of Lakshmital area pertaining *demographic information, economic status, water usage pattern, waste management and sanitation conditions availability*. The information collected was later compiled and analyzed and presented in the forms of tables and graphs.

### (D) Statistical Analysis

Correlation coefficients were calculated by Karl Pearson's method, between physico-chemical parameters and between metals to know the interdependence of variables during different seasons and in annual mean. The SPSS statistical software was used to carry out the analysis.

# Results

In the present study results have been discussed under four sections which are as follows:

(A) Physico-chemical Analysis; (B) Metals Analysis; (C) Biological Analysis; (D) Socio-economic Analysis.

## (A) Physico-chemical Analysis

A physical and chemical characteristic of water is required to assess and determine the quality to ascertain their suitability for various purposes. According to Ismail *et al.* (2005) the water chemistry of wetlands is primarily a result of the geologic setting, water balance i.e. relative proportion of inflow, outflow and storage, quality of inflowing water, types of soils and vegetation, and human activities within or near the wetland. Hydrological conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties, and pH. These modifications of the physicochemical environment, in turn, have a direct impact on the biotic response in the wetlands (Gosselink *et al.,* 1978).

In the present study, physico-chemical characteristics of Lakshmital were studied for a period of one year from May 2006 to February 2007. Seasonal status of eight selected sampling sites were recorded and compared with water quality permissible limits. The obtained results of water quality of Lakshmital outline following physico-chemical characteristics:

## Temperature

Seasonal variation of temperature (in $^0$C) at different locations of Lakshmital has been shown in **Figure 5.1.** Mean seasonal temperature for *winter* varied between 16.80$^0$C to 18.26$^0$C with an average mean value of 17.82$^0$C. Maximum value has been recorded for inflow (site I) and region adjacent to boundary wall (site IV), respectively. On contrary, minimum temperature was observed in well water near Kali temple (site VIII) as shown in **Table 5.1.** A similar trend has been followed by pre-monsoon and post-monsoon seasons with maximum temperature occurrence at site I. During *pre-monsoon season* maximum value (36.80$^0$C) at site I was followed by site VI; outflow (36.40$^0$C) and site III; middle lake region (36.06$^0$C) respectively. Watershed region (site II) exhibited the minimum value (29.23$^0$C) of temperature. An average mean value for all sites was observed 34.89$^0$C **(Table 5.2).** In *post-monsoon season* temperature varied between 28.16$^0$C and 29.23$^0$C with an average mean of 28.82$^0$C. Highest temperature (29.23$^0$C) at site I was followed by 29.13$^0$C at site V and 29.03$^0$C at site II and site IV, respectively. Lowest value (28.16$^0$C) was recorded in well water near Bhutnath temple (site VII) **(Table 5.3).** An *annual average mean* temperature was reported 27.49$^0$C which varied from 26.53$^0$C to 28.06$^0$C at site VIII and site I, respectively as shown in **Table 5.4.** Maximum annual mean temperature (28.06$^0$C) at site I was followed by site II (27.94$^0$C) and site V (27.78$^0$C); area adjacent to vegetable farms.

## pH

**Figure 5.2** represents the seasonal variation in pH at different sites of Lakshmital. Mean *winter* pH varied between 6.73 and 7.26 with an average mean of 7.02 for all sites. Maximum value (7.26) was found at site I and site IV respectively. Whereas site VIII exhibited the minimum pH value (6.73) **(Table**

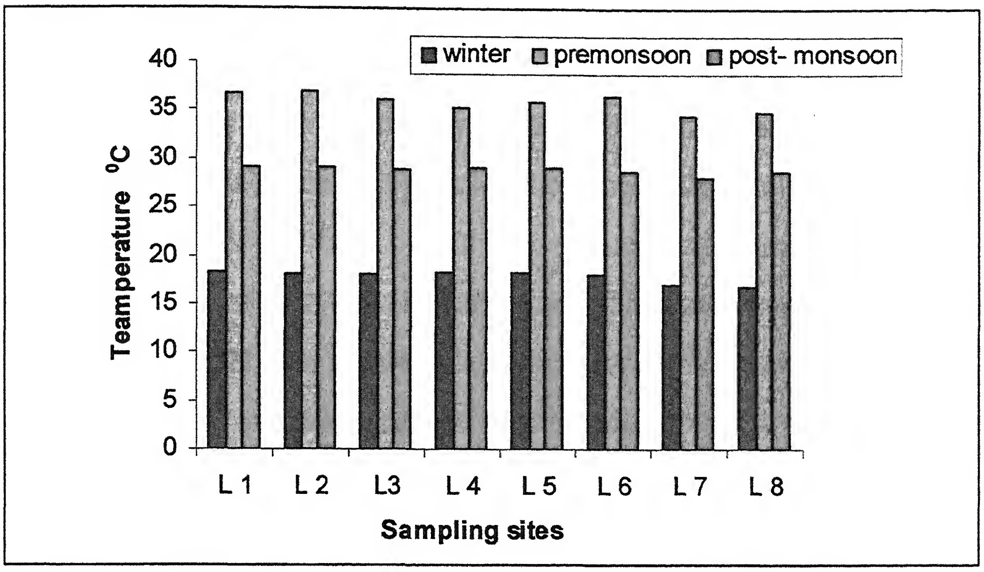



**Figure 5.1. Seasonal variation in Temperature (in $^0$C) at different locations of Lakshmital**

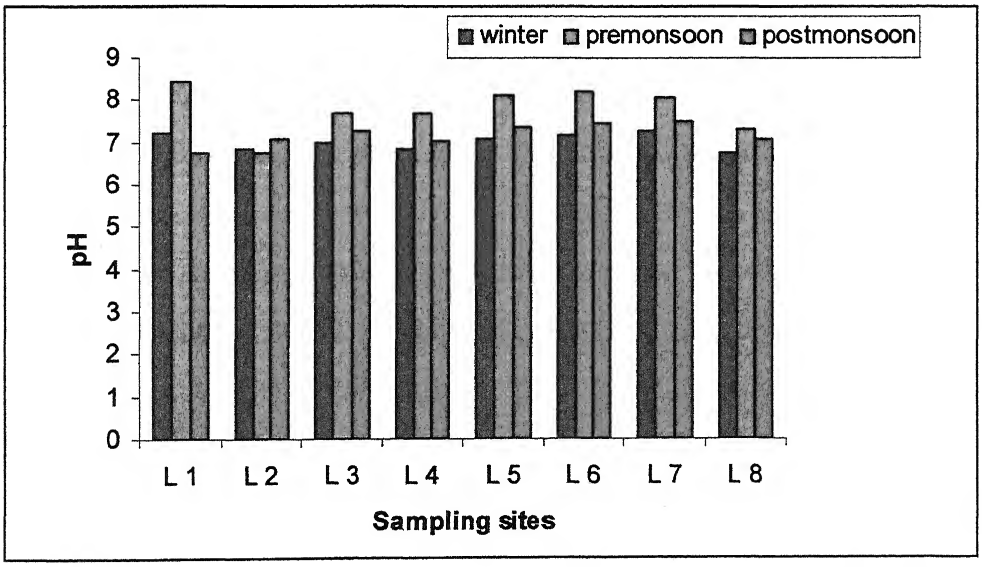



**Figure 5.2. Seasonal variation in pH at different locations of Lakshmital**

5.1). A similar trend has been observed in *pre-monsoon season* as shown in **Table 5.2.** A variation from 7.30 to 8.46 was observed with an average mean of 7.78. Maximum value (8.46) at site I was followed by 8.20, 8.10 and 8.06 at site VI, site V and site VII respectively. A different trend has been found for *post-monsoon season* as revealed by **Table 5.3**. Maximum pH (7.50) has been recorded at site VII followed by 7.43 and 7.36 at site VI and site V respectively with an average mean of 7.18. On contrary, site I exhibited the maximum value (6.73). *Annual mean* pH was recorded 7.37 that varied between 7.03 and 7.61 (**Table 5.4**). Maximum pH was recorded at site VII followed by 7.60, 7.51 and 7.47 at site VI, V and I respectively. Site VIII reported the minimum pH value that was 7.03.

## Turbidity

Seasonal variation in turbidity (in NTU) at different locations of Lakshmital is depicted by **Figure 5.3**. Mean average seasonal turbidity for *winter* was recorded 60.95 NTU with a wide variation of 10.00 to 133 NTU. Site I (133 NTU) has the highest turbid water followed by site IV, site II and site III with 100.33 NTU, 72.33 NTU and 66.66 NTU turbidity values respectively. Minimum turbidity was obtained at site VIII (**Table 5.1**). According to **Table 5.2,** mean average seasonal turbidity for *pre-monsoon season* is 61.87 NTU which varied between 8.66 to 202.66 NTU. Site II has maximum turbidity followed by site I (110.66 NTU) and site IV (58.33 NTU) respectively. Site VIII revealed the minimum turbidity value (8.66 NTU) following the previous trend. A similar trend to winter has been observed in *post-monsoon season* where mean turbidity varied from 11.33 to 202.66 NTU at site VIII and site I respectively, with an average mean value of 86.00 NTU (**Table 5.3**). *Annual average mean* turbidity was recorded 63.86 NTU with a variation between 10.00 to 148.77 NTU. Maximum turbid water was found at site I (148.77 NTU)

followed by site IV (92.88 NTU) and site II (91.55 NTU) respectively. Turbidity was the lowest in well water near Kali temple (site VIII) (**Table 5.4**).

## Electrical Conductivity

Seasonal variation in electrical conductivity (EC in µmhos/cm) at different sites of Lakshmital has been represented in **Figure 5.4**. An average mean value of EC during *winter* was observed 762.95 µmhos/cm which varied between 604.00 and 900.33 µ mhos/cm. Site IV exhibited maximum EC value (900.33 µ mhos/cm) followed by site I (831.33µ mhos/cm), site III (827.00 µ mhos/cm) and site II ( 816.66µ mhos/cm). The minimum EC (604.00 µmhos/cm) was recorded at site VII **(Table 5.1)**. A similar trend has been observed during pre-monsoon and post-monsoon seasons that showed maximum conductivity at site IV. EC during *pre-monsoon* varied from 737.66 to 1216.00 µmhos/cm at site II and site IV, respectively, with an average mean of 1005.62 µmhos/cm as shown in **Table 5.2**. During *post-monsoon season* conductivity varied from 511.00 to 812.33µmhos/cm with an average mean value of 665.33µmhos/cm. Site VII exhibited minimum value of EC (511.00 µmhos/cm) with a maximum value (812.33µmhos/cm) at site IV (**Table 5.3**). *Annual mean* average EC was recorded 827.50µmhos/cm which varied in the range of 651.66 to 976.22 µmhos/cm at site VIII and site IV respectively. The maximum conductivity value (976.22 µmhos/cm) at site IV was followed by site III (915.22 µmhos/cm), site I (902.88 µmhos/cm) and site II (888.44 µmhos/cm) as shown in **Table 5.4**.

## Total Suspended Solids

Seasonal variation in total suspended solids (TSS in mg/l) at different locations of Lakshmital has been shown in **Figure 5.5**. According to **Table 5.1** mean

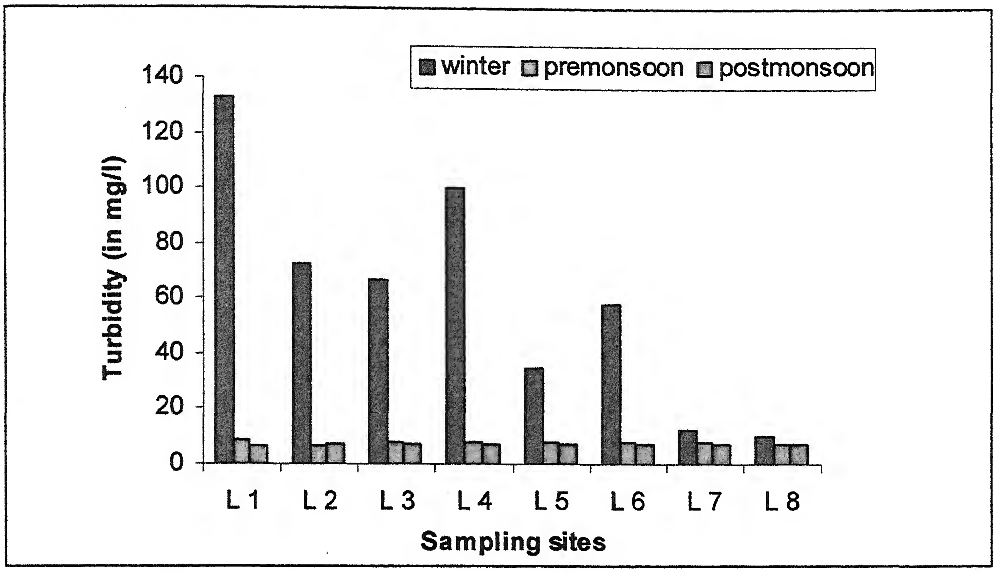



**Figure 5.3. Seasonal variation in Turbidity (in mg/l) at different locations of Lakshmital**

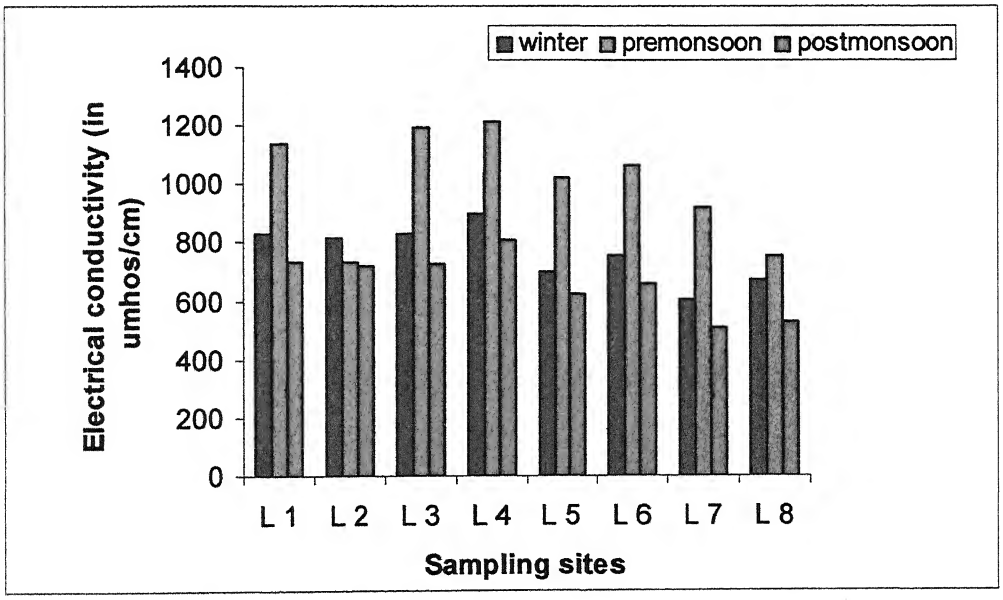



**Figure 5.4. Seasonal variation in Electrical Conductivity (in µmhos/cm) at different locations of Lakshmital**

variation in TSS during *winter season* has been observed between 153.33 and 256.66 mg/l with a mean average value of 206.83 mg/l. The maximum value was obtained at site IV followed by site III (244.00 mg/l), site II (232.00 mg/l) and site I (209.66 mg/l). The minimum TSS was observed at site VIII. However, a different trend has been found in pre-monsoon and post-monsoon seasons. A mean average value for *pre-monsoon* was recorded 301.28 mg/l which varied in range of 173.00 mg/l and 447.33 mg/l. Maximum value was observed at site II followed by site I (397.00 mg/l) and site IV (384.66 mg/l). On contrary, minimum value (173.00 mg/l) was obtained at site VII (**Table 5.2**). During *post-monsoon season* (**Table 5.3**) an average mean value of 350.66 mg/l was recorded which varied between 191.00 and 447.33 mg/l. Site I revealed maximum value followed by site IV with 426.66 mg/l, site II with 366.00 mg/l and site III with 349.66 mg/l values. Minimum value was reported at site VII. According to **Table 5.4** *annual mean* variation in TSS observed between 172.88 to 356.00 mg/l with an average mean of 272.22 mg/l. Site IV exhibited maximum TSS value (356.00 mg/l) followed by site I (351.33 mg/l), site II (302.77 mg/l) and site III (295.66 mg/l) while site VII exhibited the minimum TSS value.

## Total Dissolved Solids

**Figure 5.6** represented the seasonal variation in total dissolved solids (TDS in mg/l) at different sites of Lakshmital. The seasonal mean variation of TDS during *winter season* was found in the range of 462.66 to 669.66 mg/l with an average mean of 596.83 mg/l, shown in **Table 5.1**. The maximum TDS was obtained at site IV, followed by site VI, III and site I with 647.33 mg/l, 642.00 mg/l and 633.33 mg/l values. Minimum TDS was observed at site VII. Following the trend of winter season, pre-monsoon and post-monsoon seasons also exhibited minimum TDS at site VII. Mean seasonal TDS for *pre-monsoon*

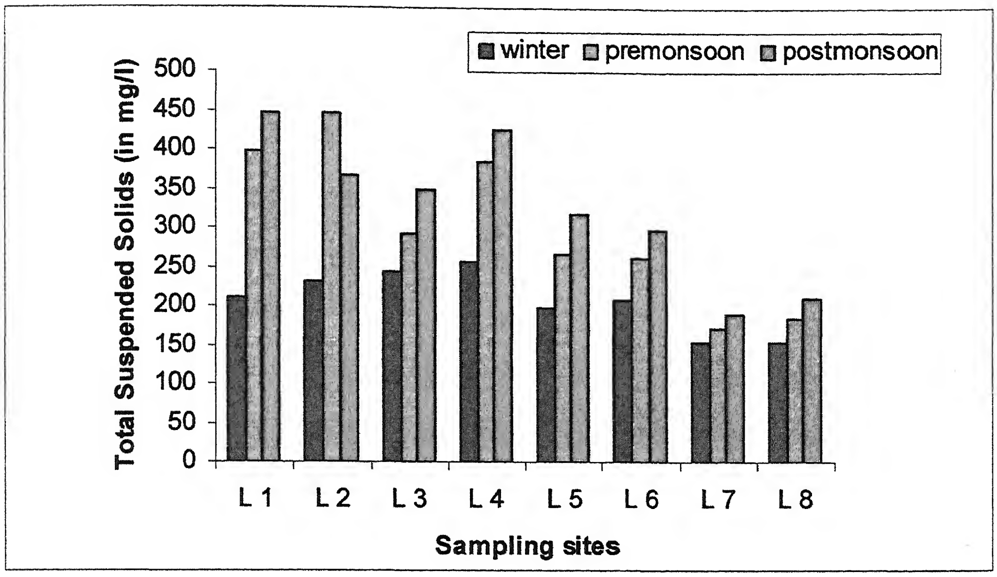



**Figure 5.5. Seasonal variation in Total Suspended Solids (in mg/l) at different locations of Lakshmital**

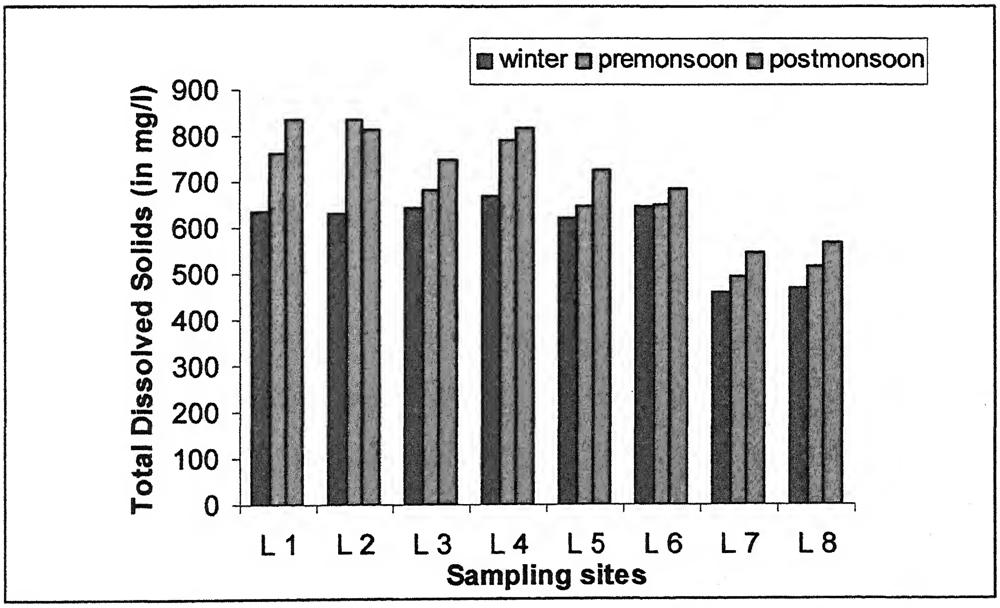



**Figure 5.6. Seasonal variation in Total Dissolved Solids (in mg/l) at different locations of Lakshmital**

*season* varied between 495.00 mg/l and 835.33 mg/l with an average mean of 673.16 mg/l. Maximum TDS has been reported at site II followed by site IV (791.33 mg/l), site I (762.33 mg/l) and site III (684.66 mg/l) (**Table 5.2**). During *post-monsoon season* mean TDS varied between 549.66 and 835.33 mg/l with an average mean of 717.95 mg/l. Site I depicted maximum TDS contents and it was followed by site IV with 815.33 mg/l, site II with 812.33 mg/l and site III with 745.66 mg/l values (**Table 5.3**). *Annual mean* variation in TDS ranged form 502.44 to 758.77 mg/l with an average value of 657.68 mg/l reported in **Table 5.4**. Maximum value has been observed at site IV followed by site I (743.66 mg/l), site II (719.22 mg/l) and site III (690.77 mg/l). A minimum TDS value (502.44mg/l) has been obtained at site VII.

## Total Solids

Seasonal variation in Total Solids (TS in mg/l) at different locations has been represented by **Figure 5.7**. Mean TS during *winter season* varied between 617.33 to 926.33 mg/l with an average of 803.66 mg/l. Maximum TS has been reported at site IV followed by site III and site II with 886.00 mg/l and 861.33 mg/l values. Site VII showed minimum TS (617.33 mg/l) (**Table 5.1**). However, a different trend has been found during pre-monsoon and post-monsoon seasons. Mean variation in TS during *pre-monsoon season* ranged between 668.00 and 1282.66 mg/l with an average mean content of 974.46 mg/l. The maximum range was observed at site II followed by site IV (1176.00 mg/l) and site I (1159.33 mg/l) while site VII showed the minimum TS contents as depicted by **Table 5.2**. During *post-monsoon season* mean TS varied from 740.66 to 1282.66 mg/l with an average mean value of 1043.62 mg/l. Maximum contents (1282.66 mg/l) were observed at site I which was followed by site IV, site II and site III with 1242.00 mg/l, 1178.33 mg/l and 1095 mg/l values. Site VII exhibited the minimum range of TS (**Table 5.3**). According to **Table 5.4**

*annual mean* TS varied between 675.33 and 1114.77 mg/l with an average mean of 929.90 mg/l. Site IV exhibited maximum concentration followed by site I (1095.00 mg/l) and site II (1022.00 mg/l). Site VII showed the minimum TS value followed by the previous trends during winter, pre-monsoon and post-monsoon seasons.

## Total Hardness

Seasonal variation in total hardness (TH in mg/l) at different locations has been shown in **Figure 5.8.** Seasonal mean variation in TH during *winter season* was observed in the range of 160.00 to 294.33 mg/l, with an average mean of 196.16 mg/l (**Table 5.1**). The maximum hardness was observed at site VIII followed by site IV, site III and site II with 205.66 mg/l, 192.00 mg/l and 185.33 mg/l values. The minimum hardness (160.00 mg/l) was obtained at site VII. Site VIII showed the maximum hardness during pre-monsoon and post-monsoon seasons following the previous trend. During *pre-monsoon* TH varied between 166.33 and 346.66 mg/l with an average mean of 223.45 mg/l. Site IV, V and VI followed the site VIII in maximum hardness range i.e., 222.66 mg/l, 220.66 mg/l and 216.66 mg/l reported in **Table 5.2**. Site II showed the lowest range (166.33 mg/l) of hardness in water. **Table 5.3** revealed the mean variation in TH during *post-monsoon season* which varied between 128.66 and 265.33 mg/l. An average mean value was obtained during the season is 172.04 mg/l. The maximum hardness (265.33 mg/l) was found at site VIII, followed by site IV (180.33 mg/l), site II (172.66 mg/l) and site I (166.33 mg/l). Site VII showed the minimum hardness value. An *annual average mean* value of TH during the study was observed 119.22 mg/l with a variation between 164.44 and 302.11 mg/l. Maximum value at site VIII was followed by site IV (202.88 mg/l), site II (190.77 mg/l) and site V (187.22 mg/l) respectively. Site VII recorded the minimum hardness (164.44 mg/l) as shown in **Table 5.4**.

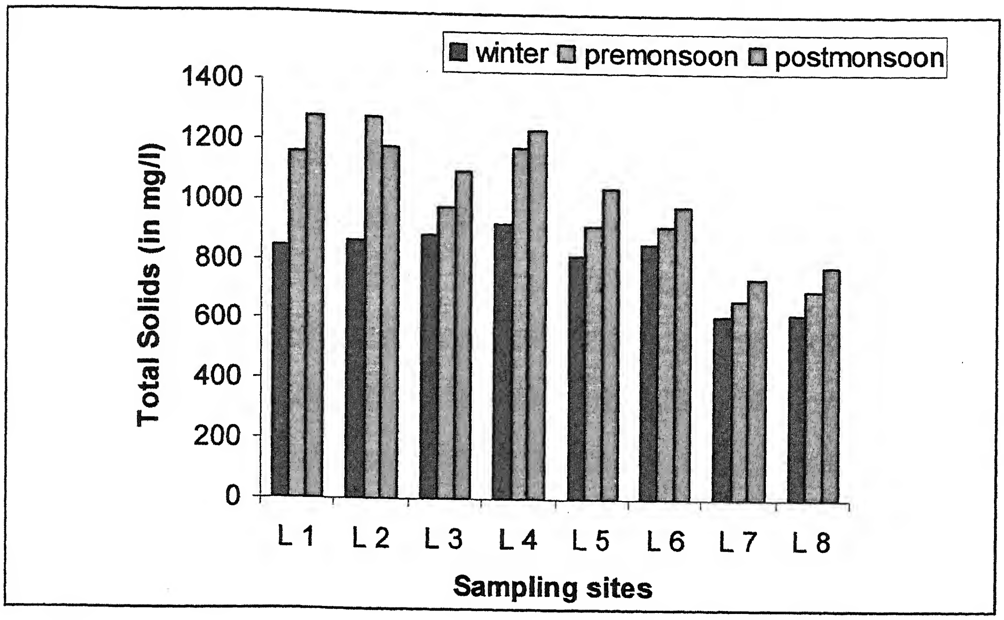



**Figure 5.7. Seasonal variation in Total Solids (in mg/l) at different locations of Lakshmital**

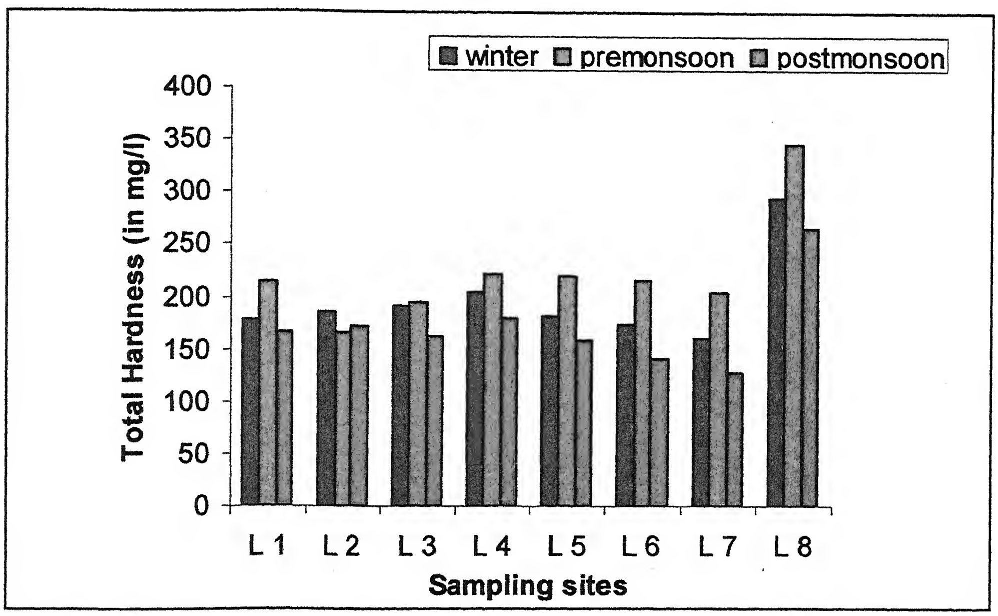



**Figure 5.8. Seasonal variation in Total Hardness (in mg/l) at different locations of Lakshmital**

## Calcium

**Figure 5.9** depicted the seasonal variation in Calcium (Ca in mg/l) at different sites of Lakshmital. According to **Table 5.1**, mean variation during the *winter season* varied between 79.66 and 212.00 mg/l with an average mean of 101.66 mg/l. Maximum value has been reported at site VIII which was followed by site III (93.33 mg/l) and site V (91.00 mg/l). Minimum value (79.66 mg/l) has been observed at site II. However, a different trend has been observed for pre-monsoon and post-monsoon seasons. During *pre-monsoon season* mean values varied from 68.66 to 223.00 mg/l with an average of 115.25 mg/l. Maximum concentration was found at site VIII followed by site III (113.33 mg/l) and site IV (110.00 mg/l) whereas site II showed the minimum concentration of Ca (**Table 5.2**). The mean variation in Ca concentration during *post-monsoon season* was observed between 65.66 and 204.33 mg/l with a mean average value of 90.95 mg/l. Maximum concentration (204.33 mg/l) was recorded at site VIII similarly as found during winter and pre-monsoon season. Site VII showed the minimum Ca contents (**Table 5.3**). According to **Table 5.4**, *annual average mean* was reported 103.87 mg/l with a variation between 82.33 to 213.11 mg/l. Maximum concentration was recorded at site VIII followed by site III (94.44 mg/l), site (92.77 mg/l) and site IV (91.44 mg/l). Site I exhibited the minimum concentration.

## Magnesium

Seasonal variation in Magnesium (Mg in mg/l) at different locations has been represented in **Figure 5.10.** Seasonal mean variation in Mg during *winter season* has been recorded between 42.66 and 121.33 mg/l with an average mean of 61.62 mg/l, shown in **Table 5.1**. Maximum concentration has been observed at site VIII followed by site V (59.66 mg/l), site IV (55.66 mg/l) and site VII

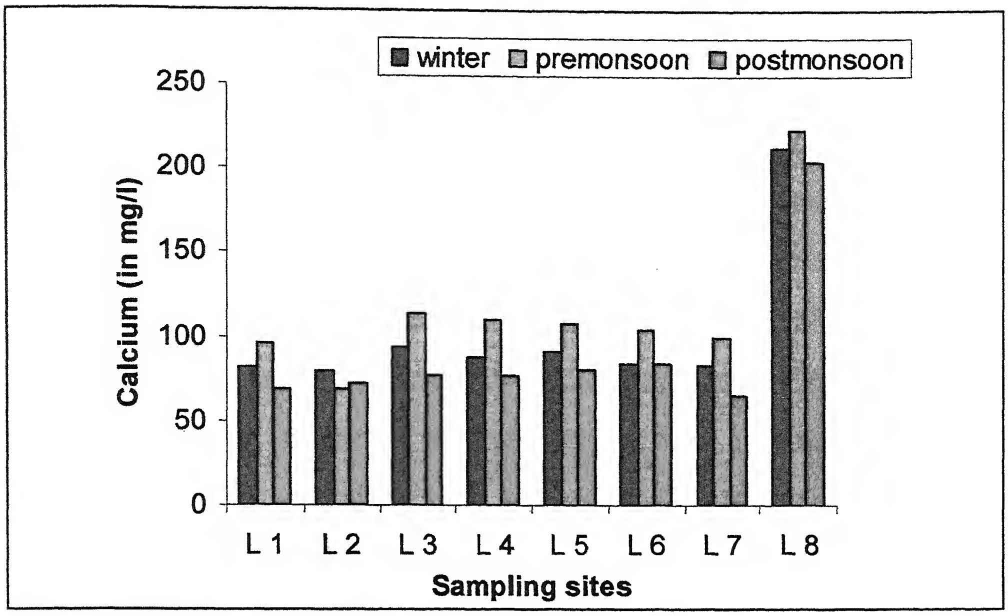



**Figure 5.9. Seasonal variation in Calcium (in mg/l) at different locations of Lakshmital**

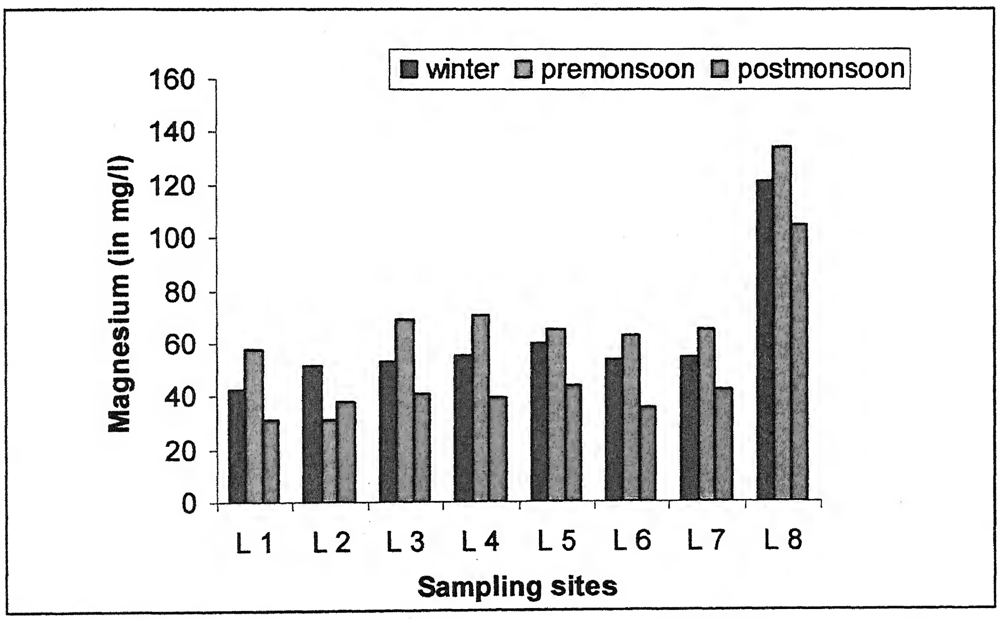



**Figure 5.10. Seasonal variation in Magnesium (in mg/l) at different locations of Lakshmital**

(54.66 mg/l). Minimum concentration was found at site I. In all seasons viz., winter, pre-monsoon and post-monsoon including annual mean values, maximum concentration has been recorded at site VIII. During *pre-monsoon season* Mg varied between 31.00 and 134.00 mg/l with an average mean of 69.33 mg/l. Site VIII (134.00 mg/l) for maximum concentration was followed by site IV (70.33 mg/l), site III (68.66 mg/l) and site VII (65.33 mg/l). Site II reported the minimum concentration (**Table 5.2**). According to **Table 5.3**, mean value for *post-monsoon season* varied between 31.00 to 104.66 mg/l with an average mean of 47.04 mg/l. Site V, site VII and site III followed site VIII for maximum concentration (104.66 mg/l) with 44.00 mg/l, 42.66 mg/l and 41.00 mg/l values. Minimum concentration was recorded at site I. *Annual mean values* varied between 43.66 and 120.00 mg/l with an average mean of 60.65 mg/l. Maximum value was observed at site VIII followed by site V (56.22 mg/l), site IV (55.22 mg/l) and site III (54.33 mg/l). Site I exhibited the minimum concentration (43.66 mg/l) of Mg (**Table 5.4**).

## Total Alkalinity

**Figure 5.11** shows seasonal variation in total alkalinity (TA in mg/l) at different locations of Lakshmital. Seasonal mean variation in TA during *winter season* has been recorded between 414.66 to 756.00 mg/l with an average mean of 588.50 mg/l. Maximum value has been recorded at site VIII followed by site III (656.66 mg/l), site IV (609.00 mg/l) and site I (588.66 mg/l). Minimum alkalinity has been reported at site IV (414.66 mg/l) as shown in **Table 5.1**. A similar trend has been observed in pre-monsoon and post-monsoon seasons where maximum alkalinity that was 807.00 mg/l and 809.66 mg/l was recorded at site VIII. The maximum value (807.00 mg/l) at site VIII in *pre-monsoon* was followed by site III (695.00 mg/l), site IV (651.33 mg/l) and site V (628.66

mg/l). The minimum value has been reported at site VI (603.00 mg/l) (**Table 5.2**).

During *post-monsoon season* with an average value of 646.46 mg/l, maximum alkalinity (809.66 mg/l) at site VIII was followed by (690.33 mg/l) at site III, (642.66 mg/l) at site IV and (617.33 mg/l) at site V. The minimum value has been recorded at site VII (563.66 mg/l) as shown in **Table 5.3**. According to **Table 5.4**, *annual average mean* alkalinity was recorded 638.75 mg/l which varied between 563.66 and 809.66 mg/l at site VI and site VIII, respectively .Site VIII with maximum alkalinity (809.66 mg/l) was followed by site III (690.33 mg/l), site IV (642.66 mg/l) and site V (617.33 mg/l).

## Chloride

Seasonal variation in Chloride (in mg/l) at different sites of Lakshmital has been shown in **Figure 5.12.** Mean seasonal chloride concentration for *winter* varied between 70.10 and 139.80 mg/l with an average mean of 103.33 mg/l (**Table 5.1**). Maximum concentration was found at site VIII (139.80 mg/l) followed by site VI (122.53 mg/l), site V (110.86 mg/l) and site VI (103.66 mg/l), respectively. The minimum concentration was reported at site II (70.10 mg/l). A similar trend has been followed in pre-monsoon and post-monsoon seasons with maximum concentration occurrence at site VIII. During *pre-monsoon* an average mean (205.19 mg/l) varied between 103.46 and 298.16 mg/l. Site VIII with the highest concentration was followed by site VII (247.50 mg/l) and site V (212.36 mg/l). Minimum chloride contents were reported at site II (103.46 mg/l) (**Table 5.2**). The mean variation for *post-monsoon* varied between 89.16 and 162.20 mg/l at site II and site VIII, respectively, with an average mean value of 123.82 mg/l. Site VII, site VI and site V followed the site VIII for maximum chloride contents with 147.43 mg/l, 135.60 mg/l and 127.56 mg/l values respectively as shown in **Table 5.3**. Annual *average mean*

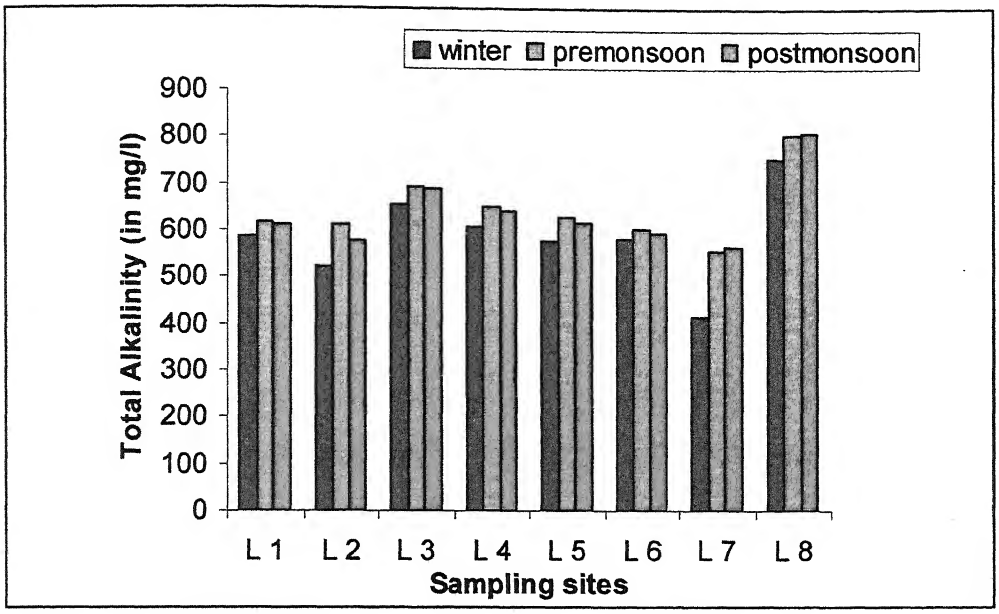



**Figure 5.11. Seasonal variation in Total Alkalinity (in mg/l) at different locations of Lakshmital**

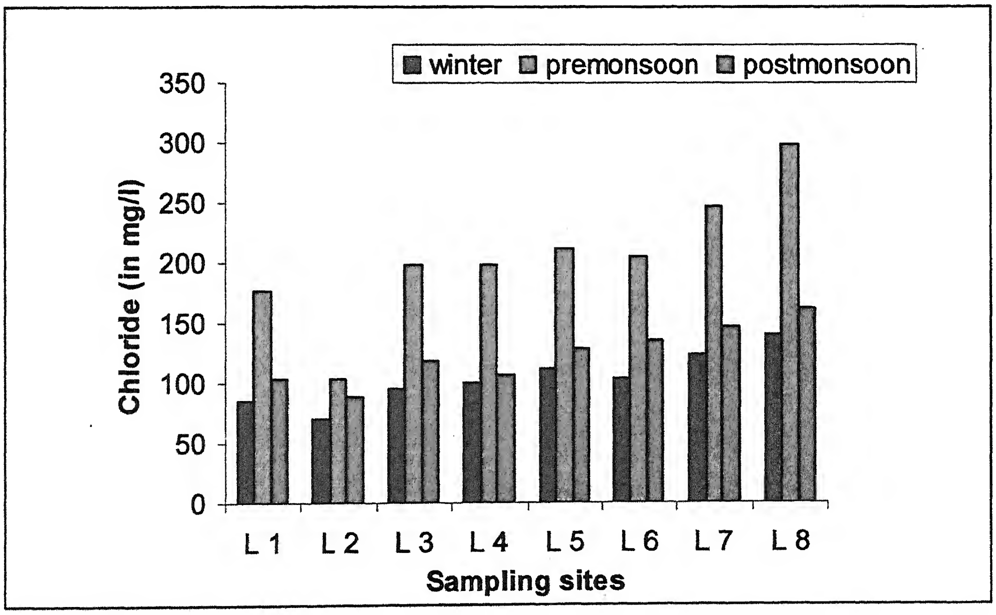



**Figure 5.12. Seasonal variation in Chloride (in mg/l) at different locations of Lakshmital**

value was observed 146.29 mg/l which varied form 105.00 to 200.05 mg/l. Maximum concentration was recorded at site VIII (200.05 mg/l) followed by site VII (172.48 mg/l), site V (150.26 mg/l) and site VI (148.20 mg/l). Minimum concentration was observed at site II (**Table 5.4**).

## Fluoride

Seasonal variation in fluoride (in mg/l) at different locations has been shown in **Figure 5.13**. Mean fluoride values for *winter* varied between 0.89 and 2.95 mg/l with an average value of 1.98 mg/l (**Table 5.1**). Site III exhibited the maximum fluoride concentration (2.95 mg/l) followed by site V (2.87 mg/l), site I (2.54 mg/l) and site II (2.49 mg/l). On contrary, minimum concentration was reported at site VIII. However, a different trend has been found for pre-monsoon and post-monsoon seasons. Maximum concentration for *pre-monsoon season* has been recorded 2.41 mg/l at site V followed by site III (2.39 mg/l) and site II (2.22 mg/l). Minimum fluoride contents were reported at site VII (0.59 mg/l) as shown in **Table 5.2**. An average mean value was obtained 1.54 mg/l. During *post-monsoon* mean variation was observed from 0.93 to 2.60 mg/l with an average mean of 1.80 mg/l. Maximum concentration was reported at site III followed by site V (2.44 mg/l) and site II (2.24 mg/l). Site VIII exhibited the minimum fluoride concentration (0.93 mg/l) (**Table5.3**). *Annual mean* fluoride concentration varied between 0.86 and 2.64 mg/l at site VIII and site III respectively with an average value of 1.76 mg/l. Maximum concentration (2.64 mg/l) at site VIII was followed by site V (2.57), site II (2.21 mg/l) and site I (2.09 mg/l) (**Table 5.4**).

## Phosphate

Seasonal variation in phosphate (in mg/l) at different locations of Lakshmital has been shown in **Figure 5.14**. Mean seasonal phosphate for *winter* varied between 0.31 to 1.20 mg/l with an average mean value of 0.75 mg/l. Maximum value (1.20 mg/l) has been recorded at site I followed by site VI (1.12 mg/l), site IV (1.10 mg/l) and site V (0.96 mg/l). On contrary, minimum phosphate concentration (0.31 mg/l) was observed at site VIII as shown in **Table 5.1**. A similar trend has been followed by pre-monsoon and post-monsoon seasons. During *pre-monsoon season* phosphate varied between 0.56 and 1.76 mg/l with an average mean of 1.28 mg/l. Site I (1.76 mg/l) for maximum concentration was followed by site VI (1.67 mg/l), site IV (1.43 mg/l) and site VI (1.35 mg/l). Site VIII reported the minimum phosphate concentration (**Table 5.2**). According to **Table 5.3**, mean value for *post-monsoon season* varied between 0.43 to 1.67 mg/l with an average mean of 1.03 mg/l. Maximum value (1.67 mg/l) at site I was followed by Site VI (1.24 mg/l), site IV (1.18 mg/l) and site V (1.09 mg/l). Minimum phosphate contents were recorded at site VIII. *Annual mean* values varied between 0.43 and 1.54 mg/l with an average mean of 0.99 mg/l. Maximum value was observed at site I followed by site VI (1.24 mg/l), site IV (1.23 mg/l) and site V (1.07 mg/l). Site VIII exhibited the minimum concentration (0.43 mg/l) of phosphate (**Table 5.4**).

## Nitrate

Seasonal variation in nitrate (in mg/l) at different locations has been represented by **Figure 5.15**. Mean nitrate during *winter season* varied between 0.22 to 4.49 mg/l with an average mean of 6.24 mg/l. Maximum concentration has been reported at site V followed by site II and site VIII with 3.48 mg/l and 0.71 mg/l values. Site VII showed minimum nitrate value (0.22 mg/l) (**Table 5.1**). A

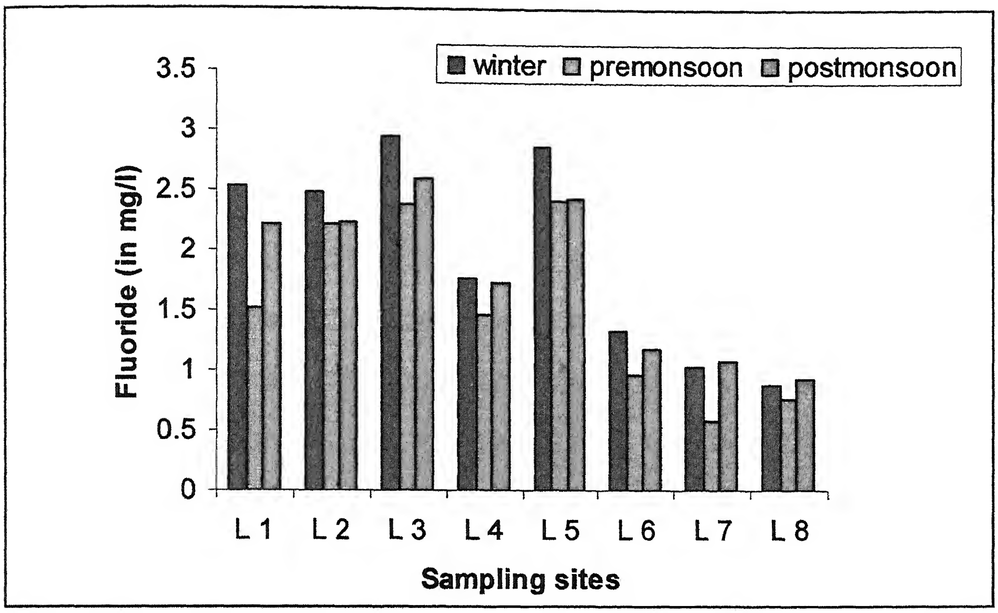



**Figure 5.13. Seasonal variation in Fluoride (in mg/l) at different locations of Lakshmital**

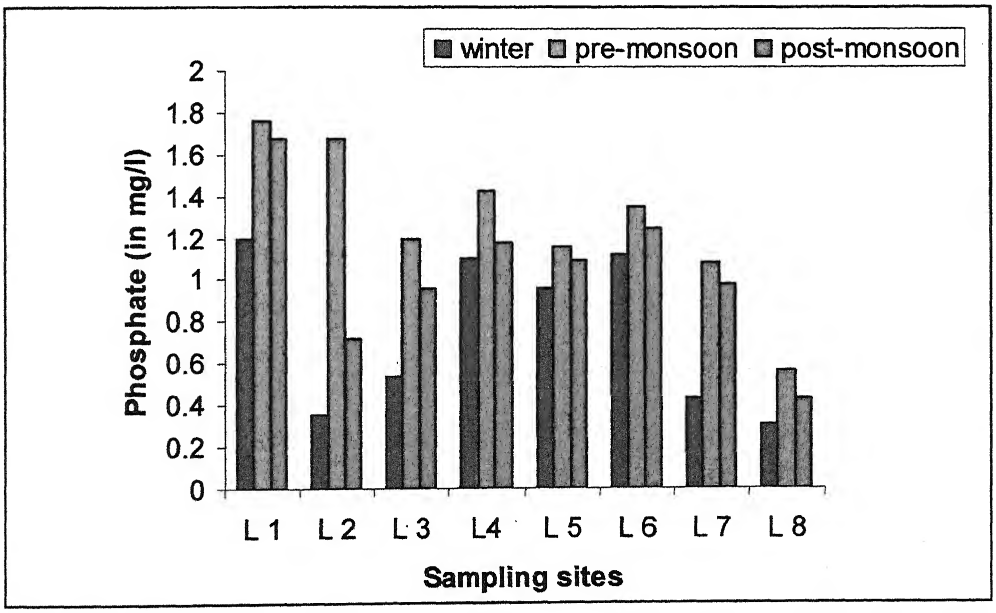



**Figure 5.14. Seasonal variation in Phosphate (in mg/l) at different locations of Lakshmital**

similar trend has been followed in pre-monsoon and post-monsoon seasons with maximum concentration occurrence at site V. During *pre-monsoon* an average mean (2.64 mg/l) varied between 0.51 and 14.45 mg/l. Site V with highest concentration was followed by site VIII (1.72 mg/l), site III (1.23 mg/l) and site I (0.92 mg/l). Minimum nitrate was reported at site VII (0.51 mg/l) (**Table 5.2**). The mean variation for *post-monsoon* varied between 0.31 and 7.13 mg/l at site VI and site V, respectively, with an average mean value of 9.70 mg/l. Site II, site VIII and site IV followed site V for maximum nitrate concentration (7.13 mg/l) with 5.37 mg/l, 1.07 mg/l and 0.89 mg/l values respectively as shown in **Table 5.3**. *Annual average mean* value was observed 9.93 mg/l which varied form 0.36 to 8.69 mg/l. Maximum concentration was recorded at site V (8.69 mg/l) followed by site II (6.03 mg/l), site VIII (1.16 mg/l) and site III (0.83 mg/l). Minimum concentration was observed at site VII (**Table 5.4**).

## Sodium

**Figure 5.16** depicted the seasonal variation in sodium (in mg/l) at different sites of Lakshmital. According to **Table 5.1**, mean variation in sodium during the *winter season* varied between 52.33 and 211.66 mg/l with an average mean of 117.75 mg/l. Maximum value has been reported at site VIII which was followed by site VII (197.33 mg/l), site IV (119.00 mg/l) and site III (106.33 mg/l). Minimum value (52.33 mg/l) has been observed at site I. A similar trend has been observed for pre-monsoon and post-monsoon seasons. During *pre-monsoon season* mean values varied from 121.00 to 283.33 mg/l with an average of 189.46 mg/l. Maximum concentration was found at site VIII (283.33 mg/l) followed by site VII (266.66 mg/l) and site IV (188.00 mg/l) while site I showed the minimum concentration of sodium (**Table 5.2**). The mean variation in sodium concentration during *post-monsoon season* was observed between 134.00 and 330.00 mg/l with a mean average value of 209.58 mg/l. Maximum

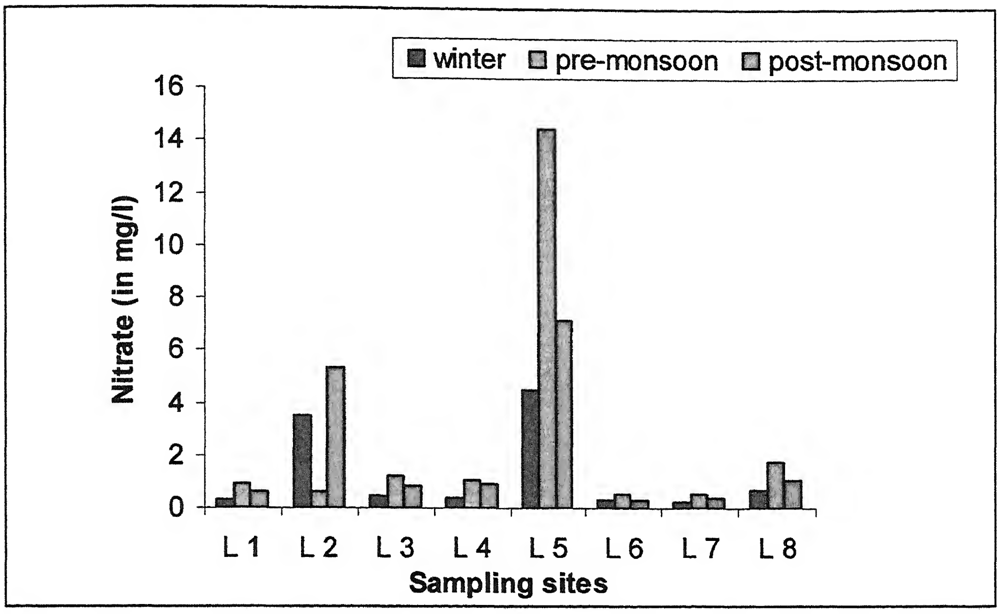



**Figure 5.15. Seasonal variation in Nitrate (in mg/l) at different locations of Lakshmital**

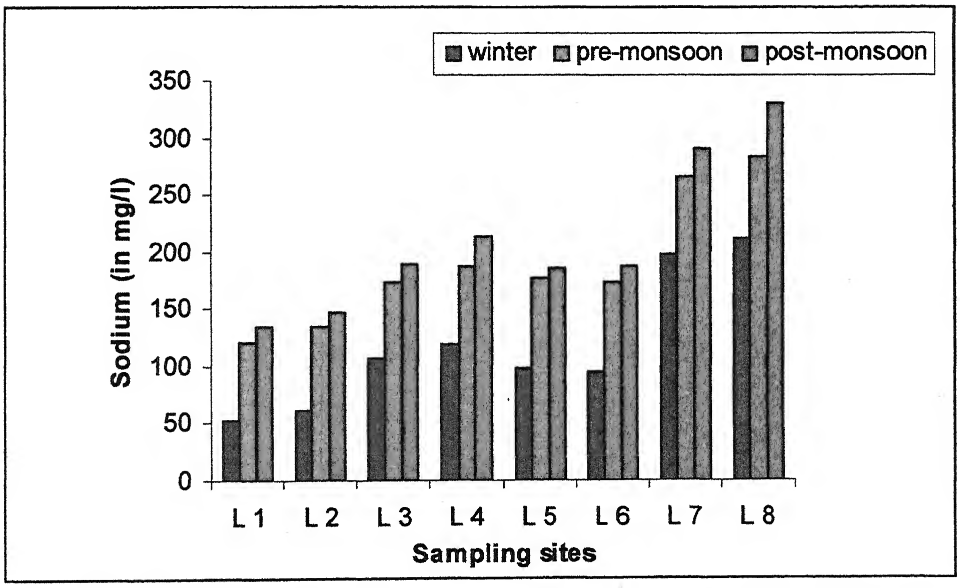



**Figure 5.16. Seasonal variation in Sodium (in mg/l) at different locations of Lakshmital**

concentration (330.00 mg/l) was recorded at site VIII followed by site VII (291.00 mg/l), site IV (213.66 mg/l) and site III (189.00 mg/l) (**Table 5.3**). According to **Table 5.4**, *annual average mean* was reported 172.09 mg/l with a variation between 102.44 to 275.00 mg/l. Maximum concentration was recorded at site VIII (275.00 mg/l) followed by site VII (251.66 mg/l), site IV (173.66 mg/l) and site III (156.33 mg/l). Site I exhibited the minimum concentration (102.44 mg/l) of sodium.

## Potassium

Seasonal variation in potassium (in mg/l) at different locations has been represented in **Figure 5.17**. Mean variation in Potassium during *winter season* has been recorded between 4.66 and 32.33 mg/l with an average mean of 18.91 mg/l, shown in **Table 5.1**. Maximum concentration has been observed at site III followed by site V (31.66 mg/l), site IV (29.33 mg/l) and site VI (22.00 mg/l). Minimum concentration (4.66 mg/l) was found at site VIII. However a different trend has been observed during pre-monsoon and post-monsoon seasons. During *pre-monsoon season* potassium varied between 14.00 and 37.66 mg/l with an average mean of 29.70 mg/l. Site V (37.66 mg/l) for maximum concentration was followed by site IV (36.66 mg/l), site VI (35.33 mg/l) and site III (34.33 mg/l). Site VIII reported the minimum concentration (**Table 5.2**). According to **Table 5.3**, mean value for *post-monsoon season* varied between 23.66 to 45.33 mg/l with an average mean of 36.45 mg/l. Site VI, site IV and site V followed site III for maximum concentration (45.33 mg/l) with 44.66 mg/l, 43.66 mg/l and 40.33 mg/l values. Minimum concentration (23.66 mg/l) was recorded at site VIII. *Annual mean* values varied between 14.11 and 37.33 mg/l with an average mean of 27.94 mg/l. Maximum value was observed at site III followed by site IV and V (36.55 mg/l) and site VI (34.00 mg/l). Site I exhibited the minimum concentration (14.11 mg/l) of potassium (**Table 5.4**).

## Ammonia

**Figure 5.18** shows seasonal variation in ammonia (in mg/l) at different locations of Lakshmital. Seasonal mean variation in ammonia during *winter season* has been recorded between 0.03 to 1.73 mg/l with an average mean of 0.76 mg/l. Maximum value has been recorded at site I followed by site II (1.45 mg/l), site III (1.42 mg/l) and site IV (0.76 mg/l). Minimum concentration has been reported at site VI (0.03 mg/l) as shown in **Table 5.1**. A similar trend has been observed for pre-monsoon and post-monsoon seasons. During *pre-monsoon season* mean values varied from 0.09 to 3.84 mg/l with an average of 1.59 mg/l. The maximum value (3.84 mg/l) at site I was followed by site III (3.19 mg/l), site II (2.35 mg/l) and site IV (1.90 mg/l). The minimum value (0.09 mg/l) has been reported at site VI **(Table 5.2)**. During *post-monsoon season* maximum concentration at site I (2.35 mg/l) was followed by (1.92 mg/l) at site II, (1.21 mg/l) at site III and (1.15 mg/l) at site IV while minimum concentration has been recorded at site VI (0.05 mg/l), following the trend. The mean average value was recorded 0.95 mg/l **(Table 5.3)**. *Annual average mean* value was observed 1.13 mg/l which varied form 0.06 to 2.64 mg/l. Maximum concentration was recorded at site I (2.64 mg/l) followed by site II (2.18 mg/l), site III (1.94 mg/l) and site IV (1.27 mg/l). Minimum concentration was observed at site VI as shown in **Table 5.4**.

## Iron

Seasonal variation in Iron (in mg/l) concentration at different locations of Lakshmital has been shown in **Figure 5.19**. According to **Table 5.1** mean variation in iron during *winter season* has been observed between 0.07 and 2.10 mg/l with a mean average value of 0.81 mg/l. The maximum value was obtained at site I (2.10 mg/l) followed by site II (1.98 mg/l), site IV (0.92 mg/l)

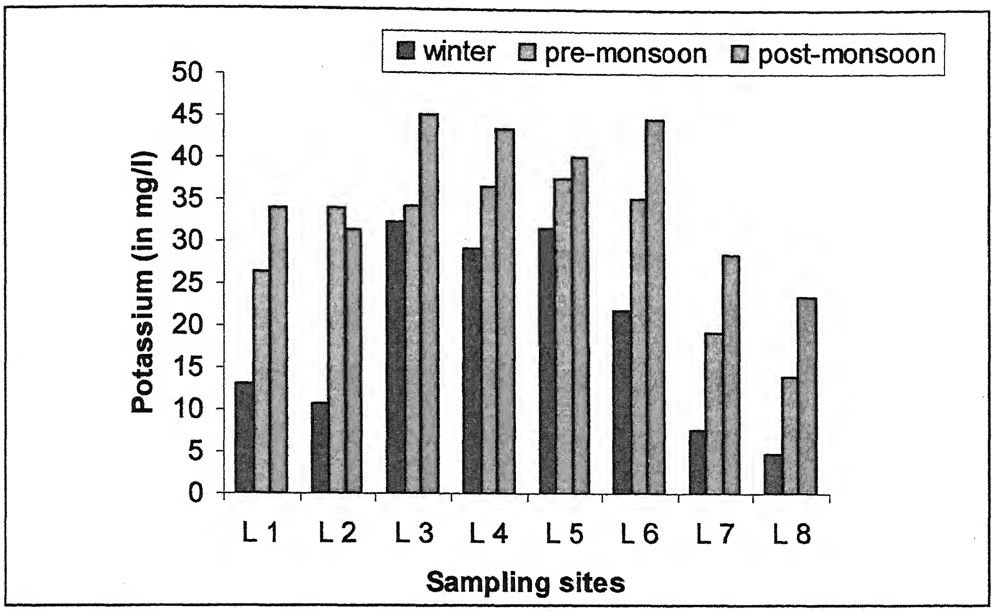



**Figure 5.17. Seasonal variation in Potassium (in mg/l) at different locations of Lakshmital**

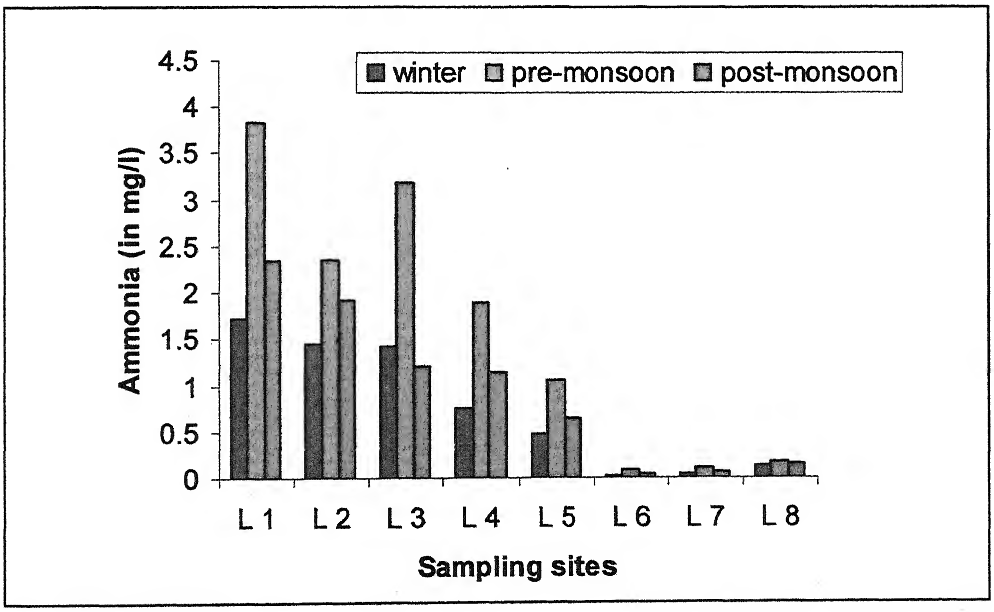



**Figure 5.18. Seasonal variation in Ammonia (in mg/l) at different locations of Lakshmital**

and site III (0.67 mg/l). The minimum iron contents (0.07 mg/l) were observed at site VII. However, a different trend has been found in pre-monsoon and post-monsoon seasons. A mean average value for *pre-monsoon* was recorded 0.96 mg/l which varied in range of 0.16 and 2.63 mg/l. Maximum value was observed at site I followed by site II (1.47 mg/l) and site IV (1.02 mg/l). On contrary, minimum value (0.16 mg/l) was obtained at site VIII (**Table 5.2**). During *post-monsoon season* (**Table 5.3**) an average mean value of 0.56 mg/l was recorded which varied between 0.04 and 1.55 mg/l. Site II revealed maximum value (1.55 mg/l) followed by site I with 1.47 mg/l, site IV with 0.58 mg/l and site III with 0.40 mg/l values. Minimum concentration was reported at site VII. According to **Table 5.4** *annual mean* variations observed between 0.12 to 2.09 mg/l with an average mean of 0.82 mg/l. Site II exhibited maximum iron concentration (2.09 mg/l) followed by site I (2.07 mg/l), site IV (0.84 mg/l) and site III (0.63 mg/l) while site VIII exhibited the minimum value (0.12 mg/l).

## Sulphate

Seasonal variation in sulphate at different locations of Lakshmital has been represented in **Figure 5.20**. Mean sulphate for *winter season* varied between 12.33 to 24.00 mg/l with an average mean value of 18.75 mg/l. Maximum value (24.00 mg/l) has been recorded at site VIII followed by site III (22.33 mg/l), site I (21.33 mg/l) and site IV (19.66 mg/l). On contrary, minimum sulphate concentration (12.33 mg/l) was observed at site VII as shown in **Table 5.1**. A different trend has been observed for pre-monsoon season but a similar trend to winter was found during post-monsoon season. In *pre-monsoon season* variation was found between 25.33 and 61.66 mg/l with an average mean of 45.45 mg/l. Site VIII (61.66 mg/l) for maximum concentration was followed by site III (50.66 mg/l), site I (48.33 mg/l) and site IV (47.33 mg/l). Site II reported

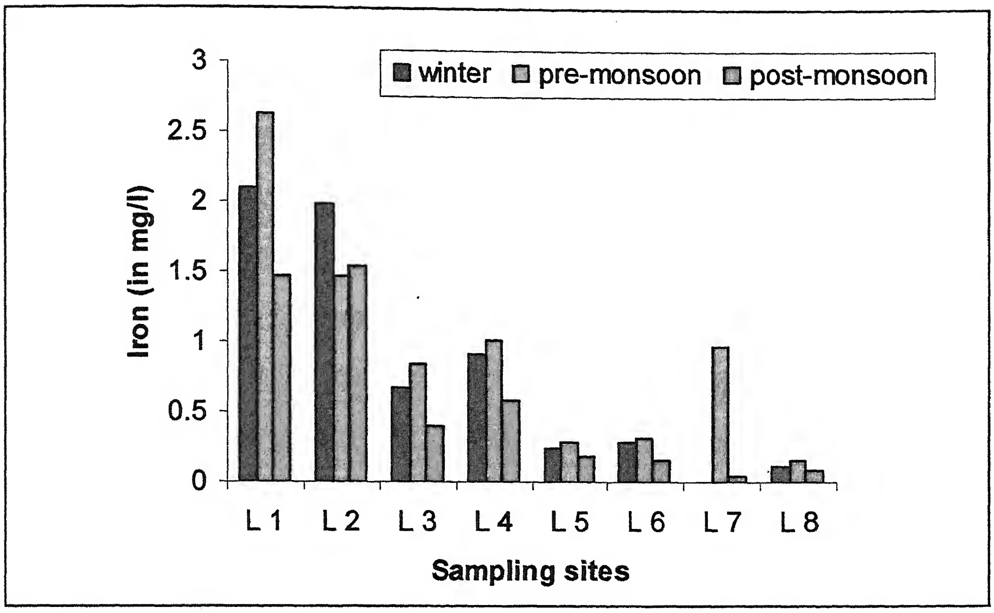



**Figure 5.19. Seasonal variation in Iron (in mg/l) at different locations of Lakshmital**

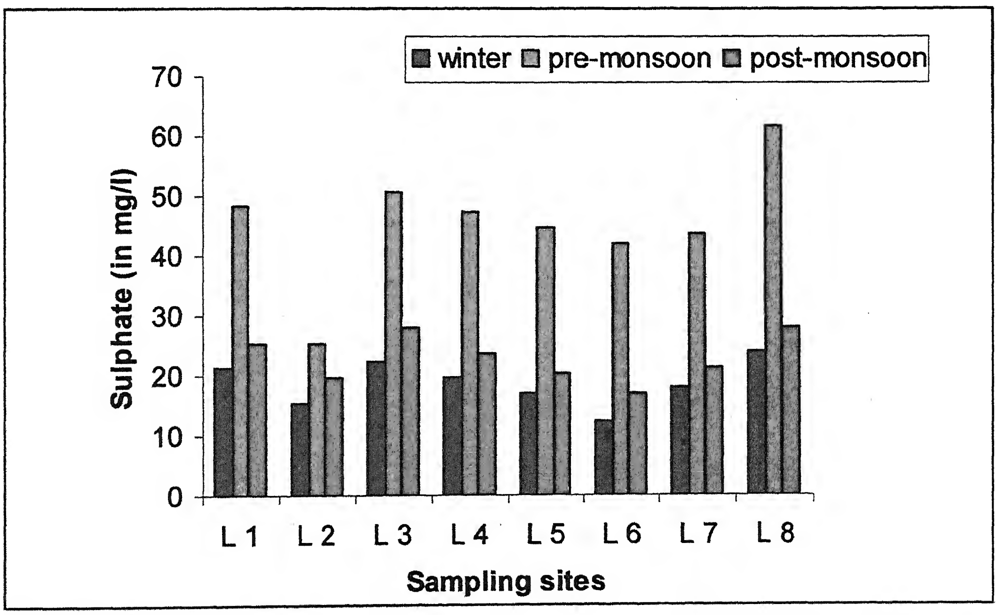



**Figure 5.20. Seasonal variation in Sulphate (in mg/l) at different locations of Lakshmital**

the minimum sulphate concentration (**Table 5.2**). According to **Table 5.3**, mean value for *post-monsoon season* varied between 17.00 to 28.00 mg/l with an average mean of 22.91 mg/l. Maximum value (28.00 mg/l) at site I and III was followed by Site I (25.33 mg/l), site IV (23.66 mg/l) and site VII (21.33 mg/l). Minimum sulphate content was recorded at site VI (17.00 mg/l). *Annual mean* values varied between 23.77 and 37.88 mg/l with an average mean of 29.91 mg/l. Maximum value was observed at site VIII followed by site III (33.66 mg/l), site I (31.66 mg/l) and site IV (30.22 mg/l). Site VI exhibited the minimum concentration (23.77 mg/l) of sulphate (**Table 5.4**).

## Dissolved Oxygen

**Figure 5.21** shows seasonal variation in dissolved oxygen (DO in mg/l) at different locations of Lakshmital. Seasonal mean variation in DO during *winter season* has been recorded between 3.86 to 9.03 mg/l with an average mean of 5.50 mg/l. Maximum value (9.03 mg/l) has been recorded at site VII followed by site VIII (7.19 mg/l), site VI (5.80 mg/l) and site III (4.79 mg/l). Minimum oxygen has been reported at site I (3.86 mg/l) as shown in **Table 5.1**. A similar trend has been observed in pre-monsoon and post-monsoon seasons where maximum dissolved oxygen 7.32 mg/l and 8.47 mg/l was recorded at site VII. The maximum value (7.32 mg/l) at site VII in *pre-monsoon* was followed by site VIII (6.10 mg/l), site II (3.25 mg/l) and site III (3.24 mg/l). The minimum value has been reported at site I (2.00 mg/l). The mean average value was recorded 3.75 mg/l (**Table 5.2**). During *post-monsoon season* maximum oxygen (8.47 mg/l) at site VII was followed by (6.89 mg/l) at site VIII, (4.76 mg/l) at site III and (4.41 mg/l) at site IV. The minimum value has been recorded at site VI (3.01 mg/l). The mean average value was found 4.84 mg/l, as shown in **Table 5.3**. According to **Table 5.4**, *annual average* mean dissolved oxygen was recorded 4.66 mg/l which varied between 3.04 and 8.27 mg/l at site I and site

VII, respectively. Site VII with maximum oxygen concentration (8.27 mg/l) was followed by site VIII (6.72 mg/l), site III (4.26 mg/l) and site VI (3.94 mg/l).

## Biochemical Oxygen Demand

The seasonal variation in biochemical oxygen demand (BOD in mg/l) at different sites of Lakshmital has been depicted in **Figure 5.22**. The seasonal mean variation of BOD during *winter season* was found in the range of 0.8 to 162.00 mg/l with an average mean of 76.10 mg/l, shown in **Table 5.1**. The maximum BOD was obtained at site I, followed by IV and site VI with 100.66 mg/l and 94.66 mg/l value whereas minimum BOD was observed at site VII. Following the trend of winter season, pre-monsoon and post-monsoon seasons also exhibited minimum BOD at site VII. Mean seasonal BOD for *pre-monsoon season* varied between 1.23 to 300.00 mg/l with an average mean of 161.60 mg/l. Maximum BOD has been reported site I (300.00 mg/l) followed by site II (224.33 mg/l) and site VI (220.33 mg/l) (**Table 5.2**). During *post-monsoon season* mean BOD varied between 1.06 and 224.33 mg/l with an average mean of 104.40 mg/l. Site I depicted maximum BOD and it was followed by site VI with 144.33 mg/l and site IV with 143.33 mg/l values (**Table 5.3**). *Annual mean* variation in BOD ranged form 1.08 to 227.22 mg/l with an average mean value of 111.35 mg/l reported in **Table 5.4**. Maximum value has been observed at site I followed by site VI (153.11 mg/l) and site IV (148.11 mg/l). A minimum BOD value (1.08 mg/l) has been obtained at site VII.

## Chemical Oxygen Demand

**Figure 5.23** shows seasonal variation in chemical oxygen demand (COD in mg/l) at different locations of Lakshmital. Seasonal mean variation in COD

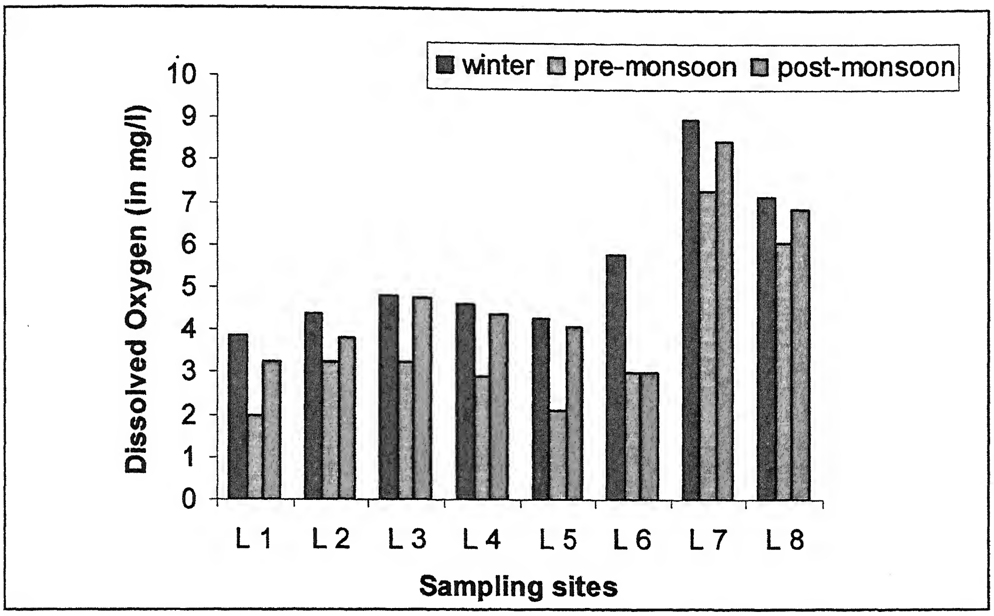



**Figure 5.21. Seasonal variation in Dissolved Oxygen (in mg/l) at different locations of Lakshmital**

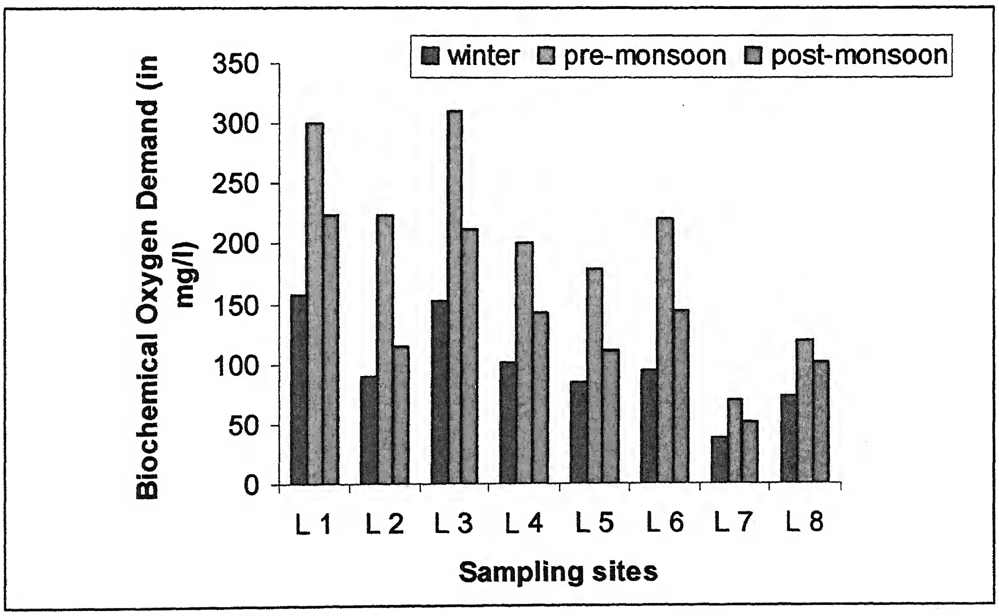



**Figure 5.22. Seasonal variation in Biochemical Oxygen Demand (in mg/l) at different locations of Lakshmital**

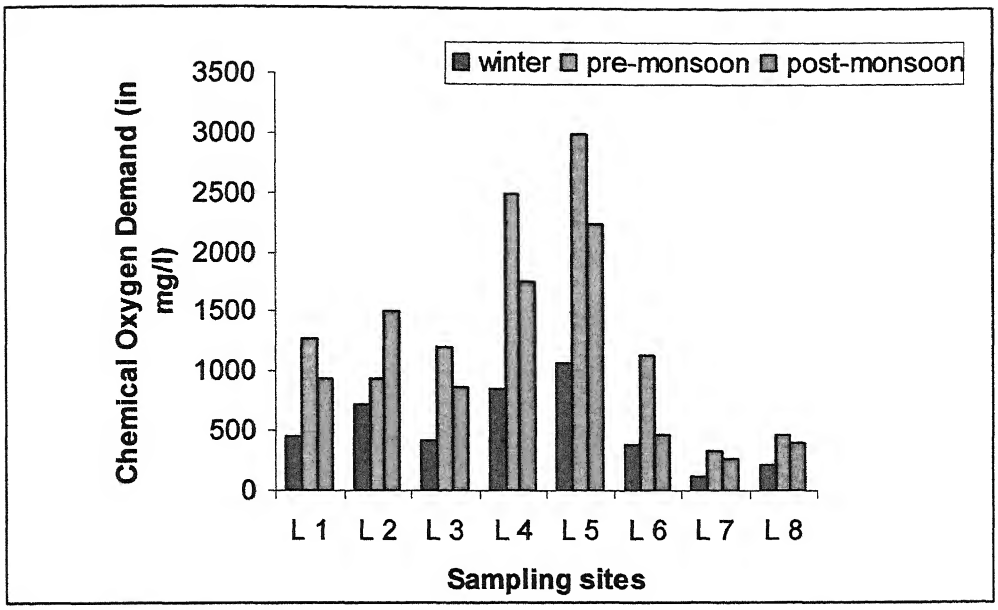



**Figure 5.23. Seasonal variation in Chemical Oxygen Demand (in mg/l) at different locations of Lakshmital**

during *winter season* has been recorded between 6.36 to 1071.66 mg/l with an average mean of 487.76 mg/l. Maximum value has been recorded at site V followed by site IV (855.33 mg/l), site II (720.66 mg/l) and site I (447.66 mg/l) with the minimum COD, reported at site VII (6.36 mg/l) as shown in **Table 5.1**. A similar trend has been observed for pre-monsoon and post-monsoon seasons. During *pre-monsoon season* mean values varied from 1.23 to 3000.00 mg/l with an average of 1260.07 mg/l. The maximum COD (3000.00 mg/l) at site V was followed by site IV (2500.33 mg/l), site I (1281.00 mg/l) and site III (1210 mg/l). The minimum value (8.96 mg/l) has been reported at site VII (**Table 5.2**). During *post-monsoon season* mean COD varied between 7.76 and 2250.00 mg/l with an average mean of 978.02 mg/l. Maximum COD at site V (2250.00 mg/l) was followed by (1765.33 mg/l) at site IV, (1501 mg/l) at site II and (938.00 mg/l) at site I while minimum COD has been recorded at site VII (7.76 mg/l), following the trend (**Table 5.3**). *Annual average* mean value was observed 958.29 mg/l which varied from 7.69 to 2107.22 mg/l. Maximum value was recorded at site V (2107.22 mg/l) followed by site IV (1707.00 mg/l), site II (1450.77 mg/l) and site IV (888.88 mg/l). The minimum COD value (7.69 mg/l) was observed at site VII as shown in **Table 5.4.**

**Table5.1. Mean values with minimum-maximum ranges of physico-chemical characteristics of Lakshmital Lake during winter season**

| Sl. No. | Parameters | Mean value ±SD (Range of values in parenthesis) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Site I | Site II | Site III | Site IV | Site V | Site VI | Site VII | Site VIII |
| 1 | Temperature ($^0C$) | 18.26±0.15 (18.10-18.40) | 17.96±0.60 (17.40-18.60) | 18.06±0.25 (17.80-18.30) | 18.20±0.20 (18.00-18.40) | 18.26±0.35 (17.90-18.60) | 18.03±0.20 (17.80-18.20) | 17.00±0.36 (16.60-17.30) | 16.80±0.34 (16.40-17.00) |
| 2 | pH | 7.23±0.25 (7.00-7.50) | 6.86±0.25 (6.60-7.10) | 7.00±0.20 (6.80-7.20) | 6.83±0.11 (6.70-6.90) | 7.06±0.15 (6.90-7.20) | 7.16±0.20 (7.00-7.40) | 7.26±0.25 (7.00-7.50) | 6.73±0.20 (6.50-6.90) |
| 3 | Turbidity (NTU) | 133.00±9.5 (124.00-133.00) | 72.33±3.05 (69.00-75.00) | 66.66±8.32 (60.00-76.00) | 100.33±5.13 (96.00-106.00) | 34.66±2.08 (33.00-37.00) | 58.00±7.00 (50.00-63.00) | 12.66±2.08 (11.00-15.00) | 10.00±1.00 (9.00-11.000 |
| 4 | Elec. Con. (μ mhos/cm) | 831.33±3.05 (828.00-834.00) | 816.66±66 (807.00-827.00) | 827.00±6.24 (820.00-832.00) | 900.33±16.01 (884.00-916.00) | 698.66±4.16 (694.00-702.00) | 755.33±3.05 (752.00-758.00) | 604.00±8.00 (596.00-612.00) | 670.33±4.16 (667.00-675.00) |
| 5 | Total suspended solids(mg/l) | 209.66±8.02 (202.00-218.00) | 232.00±31.4 (197.00-258.00) | 244.00±26.05 (217.00-269.00) | 256.66±5.68 (252.00-263.00) | 197.00±13.00 (189.00-212.00) | 207.33±3.21 (205.00-211.00) | 154.66±5.68 (150.00-161.00) | 153.33±3.05 (150.00-156.00) |
| 6 | Total dissolved solids(mg/l) | 633.33±5.50 (628.00-639.00) | 629.33±15.30 (620.00-647.00) | 642.00±7.00 (635.00-649.00) | 669.66±2.51 (667.00-672.00) | 619.66±10.26 (611.00-631.00) | 647.33±4.50 (643.00-652.00) | 462.66±17.50 (445.00-480.00) | 470.66±11.06 (459.00-481.00) |
| 7 | Total Solids (mg/l) | 843.00±2.64 (841.00-846.00) | 861.33±17.50 (844.00-879.00) | 886.00±22.91 (866.00-911.00) | 926.33±7.50 (922.00-935.00) | 816.66±9.29 (806.00-823.00) | 854.66±3.05 (852.00-858.00) | 617.33±14.01 (606.00-633.00) | 624.00±10.14 (615.00-635.00) |
| 8 | Total Hardness (mg/l) | 177.33±5.50 (172.00-183.00) | 185.33±9.29 (179.00-196.00) | 192.00±3.00 (189.00-195.00) | 205.66±26.35 (184.00-235.00) | 181.33±2.51 (179.00-184.00) | 173.33±14.74 (162.00-190.00) | 160.00±6.00 (154.00-166.00) | 294.33±14.46 (285.00-311.00) |
| 9 | Calcium (mg/l) | 82.33±3.05 (79.00-85.00) | 79.66±8.02 (72.00-88.00) | 93.33±4.04 (89.00-97.00) | 87.66±2.08 (86.00-90.00) | 91.00±12.12 (78.00-102.00) | 84.33±8.73 (77.00-94,00) | 83.00±2.64 (80.00-85.00) | 212.00±4.35 (209.00-217.00) |
| 10 | Magnesium (mg/l) | 42.66±4.04 (39.00-47.00) | 51.66±2.08 (50.00-54.00) | 53.33±7.76 (47.00-62.00) | 55.66±4.04 (52.00-60.00) | 59.66±3.21 (56.00-62.00) | 54.00±3.60 (51.00-58.00) | 54.66±5.50 (51.00-61.00) | 121.33±4.93 (118.00-127.00) |
| 11 | Total alkalinity (mg/l) | 588.66±5.85 (582.00-593.00) | 523.00±3.00 (520.00-526.00) | 656.66±7.50 649.00-664.00) | 609.00±9.84 (598.00-617.00) | 577.33±3.78 (573.00-580.00) | 582.66±2.08 (581.00-585.00) | 414.66±4.72 (411.00-420.00) | 756.00±6.00 (750.00-762.00) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12 | Chloride (mg/l) | 84.56±3.03 (81.20-87.10) | 70.10±6.22 (64.20-76.60) | 95.73±2.51 (93.90-98.60) | 99.43±12.04 (88.60-112.40) | 110.86±4.52 (105.80-114.50) | 103.66±2.74 (100.50-105.60) | 122.53±5.97 (116.30-128.20) | 139.80±2.57 (137.80-142.70) |
| 13 | Fluoride (mg/l) | 2.54±.0.25 (2.30-2.81) | 2.49±0.46 (1.96-2.83) | 2.95±0.26 (2.65-3.12) | 1.77±0.66 (1.03-2.30) | 2.87±0.23 (2.61-3.04) | 1.33±0.42 (0.91-1.76) | 1.03±0.48 (0.67-1.59) | 0.89±0.21 (0.70-1.13) |
| 14 | Phosphate (mg/l) | 1.20±0.10 (1.09-1.29) | 0.35±0.09 (0.24-0.43) | 0.54±0.11 (0.45-0.68) | 1.10±0.02 (1.08-1.13) | 0.96±0.11 (0.86-1.09) | 1.12±0.02 (1.10-1.15) | 0.43±0.05 (0.39-0.50) | 0.31±0.02 (0.29-0.34) |
| 15 | Nitrate (mg/l) | 0.28±0.03 (0.25-0.31) | 3.48±0.17 (3.36-3.68) | 0.42±0.05 (0.36-0.47) | 0.37±0.03 (0.35-0.41) | 4.49±0.69 (4.09—5.30) | 0.28±0.03 (0.25-0.32) | 0.22±0.02 (0.20-0.24) | 0.71±0.01 (0.70-0.73) |
| 16 | Sodium (mg/l) | 52.33±5.85 (48.00-59.00) | 61.66±4.16 (57.00-65.00) | 106.33±4.04 (102.00-110.00) | 119.33±10.5 (108.00-129.00) | 98.66±12.34 (85.00-109.00) | 94.66±3.05 (92.00-98.00) | 197.33±18.17 (177.00-212.00) | 211.66±3.51 (208.00-215.00) |
| 17 | Potassium (mg/l) | 13.00±2.64 (11.00-16.00) | 10.66±3.05 (8.00-14.00) | 32.33±3.05 (29.00-35.00) | 29.33±6.11 (24.00-36.00) | 31.66±1.52 (30.00-33.00) | 22.00±7.93 (16.00-31.00) | 7.66±2.51 (5.00-10.00) | 4.66±2.08 (3.00-7.00) |
| 18 | Ammonia (mg/l) | 1.73±.0.04 (1.69-1.78) | 1.45±0.02 (1.43-1.47) | 1.42±0.07 (1.37-1.51) | 0.76±0.07 (0.68-0.81) | 0.47±0.03 (0.44-0.50) | 0.03±0.01 (0.02-0.05) | 0.04±0.01 (0.03-0.06) | 0.12±0.04 (0.08-0.17) |
| 19 | Iron (mg/l) | 2.10±0.02 (2.08-2.13) | 1.98±0.16 (1.79-2.10) | 0.67±0.03 (0.64-0.70) | 0.92±0.03 (0.89-0.96) | 0.25±0.02 (0.23-0.27) | 0.29±0.06 (0.22-0.35) | 0.07±0.02 (0.05-0.10) | 0.12±0.03 (0.10-0.16) |
| 20 | Sulphate (mg/l) | 21.33±3.78 (17.00-24.00) | 15.33±2.08 (13.00-17.00) | 22.33±3.05 (19.00-25.00) | 19.66±2.51 (17.00-22.00) | 17.00±4.31 (15.00-19.00) | 12.33±2.08 (10.00-14.00) | 18.00±2.64 (16.00-21.00) | 24.00±3.60 (20.00-27.00) |
| 21 | D O (mg/l) | 3.86±.23 (3.63-4.10) | 4.41±0.06 (4.35-4.47) | 4.79±0.16 (4.61-4.92) | 4.60±0.02 (4.58-4.62) | 4.31±0.02 (4.28-4.33) | 5.80±1.56 (4.79-7.61) | 9.03±0.03 (8.99-9.06) | 7.19±0.07 (7.12-7.27) |
| 22 | B O D (mg/l) | 157.33±5.03 (152.00-162.00) | 90.00±5.29 (84.00-94.00) | 152.66±9.86 (146.00-164.00) | 100.66±6.11 (94.00-106.00) | 85.33±18.58 (64.00-98.00) | 94.66±11.01 (84.00-106.00) | 37.33±2.51 (35.00-40.00) | 72.33±3.51 (69.00-76.00) |
| 23 | C O D (mg/l) | 447.66±5.85 (441.00-452.00) | 720.66±10.01 (713.00-732.00) | 413.00±2.64 (410.00-415.00) | 855.33±7.76 (849.00-864.00) | 1071.66±5.68 (1067.00-1078.00) | 380.33±9.86 (369.00-387.00) | 124.66±3.51 (121.00-128.00) | 210.33±2.51 (208.00-213.00) |

**Table. 5.2. Mean values with minimum-maximum ranges of physico-chemical characteristics of Lakshmital Lake during pre-monsoon season**

| Sl. No. | Parameters | Mean value ±SD (Range of values in parenthesis) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Site I | Site II | Site III | Site IV | Site V | Site VI | Site VII | Site VIII |
| 1 | Temperature ($^0$C) | 36.80±0.26 (36.40-36.90) | 29.23±0.64 (28.50-29.70) | 36.06±0.68 (35.03-36.60) | 35.30±0.43 (35.00-35.80) | 35.96±0.49 (35.40-36.30) | 36.40±0.45 (36.00-36.90) | 34.43±0.30 (34.10-34.70) | 34.92±0.45 (34.80-35.00) |
| 2 | pH | 8.46±0.15 (8.30-8.60) | 6.73±0.20 (6.50-6.90) | 7.70±0.43 (7.20-8.00) | 7.70±0.20 (7.50-7.90) | 8.10±0.20 (7.90-8.30) | 8.20±0.20 (8.00-8.40) | 8.06±0.20 ((7.90-8.30) | 7.30±0.36 (7.00-7.70) |
| 3 | Turbidity (NTU) | 110.66±6.65 (105.00-118.00) | 202.66±16.19 (184.00-213.00) | 41.33±4.04 (37.00-45.00) | 58.33±11.93 (50.00-72.00) | 28.33±2.51 (26.00-31.00) | 34.66±6.65 (29.00-42.00) | 10.33±1.52 (9.00-12.00) | 8.66±0.57 (8.00-9.00) |
| 4 | Elec. Cond. (µ mhos/cm) | 1139.66±1.52 (1138.00-1141.00) | 737.66±3.51 (734.00-741.00) | 1192.66±2.51 (1190.00-1195.00) | 1216.00±9.84 (1205.00-1224.00) | 1021.66±8.50 (1012.00-1028.00) | 1065.33±4.16 (1062.00-1070.00) | 918.00±2.64 (916.00-921.00) | 754.00±5.56 (749.00-760.00) |
| 5 | Total suspended solids(mg/l) | 397.00±40.26 (353.00-432.00) | 447.33±6.02 (441.00-453.00) | 293.33±6.65 (289.00-291.00) | 384.66±24.70 (362.00-411.00) | 267.33±4.04 (263.00-271.00) | 262.00±4.35 (259.00-267.00) | 173.00±6.24 (168.00-180.00) | 185.66±5.68 (181.00-192.00) |
| 6 | Total dissolved solids(mg/l) | 762.33±5.68 (756.00-767.00) | 835.33±8.73 (828.00-845.00) | 684.66±14.01 (671.00-699.00) | 791.33±21.38 (778.00-816.00) | 648.33±2.51 (646.00-651.00) | 653.00±4.58 (649.00-658.00) | 495.00±11.00 (484.00-506.00) | 515.33±3.21 (513.00-519.00) |
| 7 | Total Solids (mg/l) | 1159.33±37.42 (1117.00-1188.00) | 1282.66±12.34 (1269.00-1293.00) | 978.00±20.29 (960.00-1000.00) | 1176.00±45.39 (1140.00-1227.00) | 915.66±5.77 (909.00-919.00) | 915.00±3.60 (911.00-918.00) | 668.00±7.81 (663.00-677.00) | 701.00±8.71 (695.00-711.00) |
| 8 | Total Hardness (mg/l) | 214.00±4.00 (210.00-218.00) | 166.33±8.32 (157.00-173.00) | 196.00±50.26 (138.00-227.00) | 222.66±23.43 (196.00-240.00) | 220.66±2.51 (218.00-223.00) | 216.66±2.08 (215.00-219.00) | 204.66±13.57 (192.00-219.00) | 346.66±2.51 (344.00-349.00) |
| 9 | Calcium (mg/l) | 96.00±3.60 (92.00-99.00) | 68.66±5.68 (64.00-75.00) | 113.33±3.05 (110.00-116.00) | 110.00±9.16 (100.00-118.00) | 107.33±2.08 (105.00-109.00) | 104.00±6.00 (98.00-110.00) | 99.66±9.60 (91.00-110.00) | 223.00±4.00 (219.00-227.00) |
| 10 | Magnesium (mg/l) | 57.33±5.50 (52.00-63.00) | 31.00±8.71 (21.00-37.00) | 68.66±2.51 (66.00-71.00) | 70.33±4.93 (67.00-76.00) | 65.00±3.60 (62.00-69.00) | 63.00±4.58 (59.00-68.00) | 65.33±2.51 (63.00-68.00) | 134.00±4.00 (130.00-138.00) |
| 11 | Total alkalinity (mg/l) | 616.66±7.02 (610.00-624.00) | 613.00±2.64 (611.00-616.00) | 695.00±3.60 (692.00-699.00) | 651.33±9.45 (644.00-662.00) | 628.66±3.51 (625.00-632.00) | 603.00±5.56 (598.00-609.00) | 557.00±3.60 (554.00-561.00) | 807.00±4.58 (803.00-812.00) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12 | Chloride (mg/l) | 177.06±6.24 (171.30-183.70) | 103.46±5.38 (97.40-107.70) | 198.83±7.91 (192.50-207.70) | 198.80±11.77 (185.70-208.50) | 212.36±4.82 (208.30-217.70) | 205.36±6.20 (199.00-211.60) | 247.50±2.90 (244.50-250.30) | 298.16±5.97 292.80-304.60) |
| 13 | Fluoride (mg/l) | 1.51±0.36 (1.22-1.93) | 2.22±0.43 (1.74-2.58) | 2.39±0.17 (2.20-2.55) | 1.47±0.40 (1.03-1.82) | 2.41±0.22 (2.23-2.67) | 0.97±0.15 (0.80-1.11) | 0.59±0.31 (0.30-0.93) | 0.77±0.12 (0.68-0.91) |
| 14 | Phosphate (mg/l) | 1.76±0.05 (1.70-1.81) | 1.67±0.08 (1.60-1.76) | 1.20±0.03 (1.17-1.24) | 1.43±0.03 (1.40-1.47) | 1.16±0.04 (1.12-1.20) | 1.35±0.02 (1.33-1.38) | 1.08±0.03 (1.05-1.11) | 0.56±0.04 (0.51-0.60) |
| 15 | Nitrate (mg/l) | 0.92±0.06 (0.85-0.98) | 0.60±0.03 (0.58-0.64) | 1.23±0.03 1.21-1.28) | 1.10±0.02 (1.08-1.13) | 14.45±1.06 (13.28-15.36) | 0.56±0.02 (0.54-0.59) | 0.51±0.10 (0.41-0.61) | 1.72±0.02 (1.70-1.75) |
| 16 | Sodium (mg/l) | 121.00±5.56 (116.00-127.00) | 134.00±7.54 (127.00-142.00) | 173.66±3.21 (170.00-176.00) | 188.00±2.64 (186.00-191.00) | 176.33±8.32 (167.00-183.00) | 172.66±1.52 (171.00-174.00) | 266.66±4.93 (261.00-270.00) | 283.33±2.08 (281.00-285.00) |
| 17 | Potassium (mg/l) | 26.33±6.11 (21.00-33.00) | 34.00±5.56 (28.00-39.00) | 34.33±3.05 (31.00-37.00) | 36.66±3.51 (33.00-40.00) | 37.66±5.50 (32.00-43.00) | 35.33±1.52 (34.00-37.00) | 19.33±3.05 (16.00-22.00) | 14.00±3.60 (10.00-17.00) |
| 18 | Ammonia (mg/l) | 3.84±0.16 (3.73-4.03) | 2.35±0.04 (2.31-2.39) | 3.196±0.02 (3.17-3.22) | 1.90±0.11 (1.79-2.01) | 1.05±0.05 (1.01-1.12) | 0.09±0.02 (0.07-0.11) | 0.10±0.04 (0.07-0.15) | 0.18±0.13 (0.03-0.28) |
| 19 | Iron (mg/l) | 2.63±0.07 (2.59-2.72) | 1.47±0.06 (1.40-1.52) | 0.84±0.02 (0.82-0.86) | 1.02±0.05 (0.97-1.08) | 0.28±0.01 (0.27-0.30) | 0.31±0.04 (0.26-0.35) | 0.97±0.04 (0.93-1.02) | 0.16±0.03 (0.12-0.19) |
| 20 | Sulphate (mg/l) | 48.33±4.04 (44.00-52.00) | 25.33±3.05 (22.00-28.00) | 50.66±2.51 (48.00-53.00) | 47.33±4.16 (44.00-52.00) | 44.66±1.52 (43.00-46.00) | 42.00±4.35 (39.00-47.00) | 43.66±1.52 (42.00-45.00) | 61.66±2.08 (60.00-64.00) |
| 21 | D O (mg/l) | 2.00±0.52 (1.67-2.61) | 3.25±0.25 (2.96-3.41) | 3.24±0.27 (2.98-3.52) | 2.92±0.03 (2.89-2.95) | 2.13±0.07 (2.06-2.21) | 3.01±0.07 (2.95-3.10) | 7.32±0.03 (7.30-7.36) | 6.10±0.03 (6.07-6.14) |
| 22 | B O D (mg/l) | 300.00±10.14 (289.00-309.00) | 224.33±2.08 (222.00-226.00) | 310.66±2.51 (308.00-313.00) | 200.33±10.26 (189.00-209.00) | 179.00±7.54 (172.00-187.00) | 220.33±3.05 (217.00-223.00) | 70.00±3.60 (67.00-74.00) | 119.66±3.05 (117.00-123.00) |
| 23 | C O D (mg/l) | 1281.00±6.24 (1276.00-1288.00) | 938.00±16.64 (926.00-957.00) | 1210.66±5.50 (1205.00-1216.00) | 2500.33±6.65 (2496.00-2508.00) | 3000.00±181.35 (2803.00-3160.00) | 1132.33±6.02 (1126.00-1138.00) | 340.33±3.51 (337.00-340.33) | 472.00±6.24 (465.00-477.00) |

**Table 5.3. Mean values with minimum-maximum ranges of physico-chemical characteristics of Lakshmital Lake during post-monsoon season**

| S.No | Parameters | Mean value ±SD (Range of values in parenthesis) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Site I | Site II | Site III | Site IV | Site V | Site VI | Site VII | Site VIII |
| 1 | Temperature ($^0C$) | 29.23±0.64 (28.50-29.70) | 29.03±0.25 (28.80-29.30) | 29.00±0.50 (28.50-29.50) | 29.03±0.49 (28.70-29.60) | 29.13±0.15 (29.00-29.13) | 28.70±0.40 (28.30-29.10) | 28.16±0.20 (28.00-28.40) | 28.33±0.45 (27.90-28.80) |
| 2 | pH | 6.73±0.20 (6.50-6.90) | 7.10±0.20 (6.90-7.30) | 7.26±0.20 (7.10-7.50) | 7.03±0.15 (6.90-7.20) | 7.36±0.25 (7.10-7.60) | 7.43±0.30 (7.10-7.70) | 7.50±0.45 (7.00-7.90) | 7.06±0.25 (6.80-7.30) |
| 3 | Turbidity (NTU) | 202.66±16.19 (184.00-213.00) | 137.66±1.52 (136.00-139.00) | 73.66±8.14 (68.00-83.00) | 120.00±3.00 (117.00-123.00) | 49.00±2.64 (47.00-52.00) | 78.00±10.53 (68.00-89.00) | 15.66±4.04 (12.00-20.00) | 11.33±0.57 (11.00-12.00) |
| 4 | Electrical con. (µ mhos/cm) | 737.66±3.51 (734.00-741.00) | 722.33±2.08 (720.00-724.00) | 726.00±4.58 (722.00-731.00) | 812.33±3.21 (810.00-816.00) | 623.33±2.08 (621.00-625.00) | 659.33±5.50 (654.00-665.00) | 511.00±3.60 (508.00-515.00) | 530.66±3.51 (527.00-534.00) |
| 5 | Total suspended solids(mg/l) | 447.33±6.02 (441.00-453.00) | 366.00±2.64 (364.00-369.00) | 349.66±7.50 (342.00-357.00) | 426.66±10.96 (418.00-439.00) | 317.33±3.51 (314.00-321.00) | 297.33±2.51 (295.00-300.00) | 191.00±7.00 (186.00-199.00) | 210.00±9.53 (201.00-220.00) |
| 6 | Total dissolved solids(mg/l) | 835.33±8.73 (828.00-845.00) | 812.33±4.72 (807.00-816.00) | 745.66±3.51 (742.00-749.00) | 815.33±25.14 (787.00-835.00) | 727.00±4.58 (723.00-732.00) | 687.33±11.37 (678.00-700.00) | 549.66±7.50 (542.00-557.00) | 571.00±2.64 (569.00-574.00) |
| 7 | Total Solids (mg/l) | 1282.66±12.34 (1269.00-1293.00) | 1178.33±2.51 (1176.00-1181.00) | 1095.33±4.04 (1091.00-1099.00) | 1242.00±32.14 (1205.00-1263.00) | 1044.33±7.50 (1040.00-1053.00) | 984.66±12.01 (973.00-997.00) | 740.66±9.71 (730.00-749.00) | 781.00±7.93 (775.00-790.00) |
| 8 | Total Hardness (mg/l) | 166.33±8.32 (157.00-173.00) | 172.66±3.05 (170.00-176.00) | 162.00±17.57 (149.00-182.000 | 180.33±6.02 (174.00-186.00) | 159.66±3.05 (157.00-163.00) | 141.33±3.51 (138.00-145.00) | 128.66±4.50 (124.00-133.00) | 265.33±2.51 (263.00-268.00) |
| 9 | Calcium (mg/l) | 68.66±5.68 (64.00-75.00) | 72.00±3.60 (69.00-76.00) | 76.66±6.11 (70.00-82.00) | 76.66±8.50 (68.00-85.00) | 80.00±6.55 (74.00-87.00) | 83.66±2.51 (81.00-86.00) | 65.66±5.68 (61.00-72.00) | 204.33±3.05 (202.00-207.00) |
| 10 | Magnesium (mg/l) | 31.00±8.71 (21.00-37.00) | 37.66±4.16 (33.00-41.00) | 41.00±6.24 (36.00-48.00) | 39.66±4.16 (35.00-43.00) | 44.00±3.60 (40.00-47.00) | 35.66±2.51 (33.00-38.00) | 42.66±1.52 (41.00-44.00) | 104.66±2.08 (103.00-107.00) |
| 11 | Total alkalinity (mg/l) | 613.00±2.64 (611.00-616.00) | 579.33±9.29 (569.00-587.00) | 690.33±3.05 (687.00-693.00) | 642.66±3.51 (639.00-646.00) | 617.33±3.51 (614.00-621.00) | 594.00±3.60 (590.00-597.00) | 563.66±2.51 (561.00-566.00) | 809.66±2.08 (808.00-812.00) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12 | Chloride (mg/l) | 103.46±5.38 (97.40-107.70) | 89.16±4.33 (85.40-93.90) | 118.20±1.83 (116.60-120.20) | 106.96±4.40 (102.50-111.30) | 127.56±6.01 (123.80-134.50) | 135.60±5.69 (129.20-140.10) | 147.43±3.35 (143.70-150.20) | 162.20±2.62 (160.30-165.20) |
| 13 | Fluoride (mg/l) | 2.22±0.43 (1.74-2.58) | 2.24±0.18 (2.05-2.41) | 2.60±0.27 (2.30-2.84) | 1.73±0.19 (1.53-1.91) | 2.44±0.33 (2.08-2.74) | 1.19±0.16 (1.02-1.34) | 1.09±0.26 (0.83-1.35) | 0.93±0.20 (0.70-1.08) |
| 14 | Phosphate (mg/l) | 1.67±0.08 (1.60-1.76) | 0.72±0.01 (0.71-0.74) | 0.96±0.05 (0.92-1.02) | 1.18±0.04 (1.14-1.23) | 1.09±0.02 (1.07-1.12) | 1.24±0.03 (1.21-.128) | 0.98±0.06 (0.93-1.05) | 0.43±0.02 (0.41-0.46) |
| 15 | Nitrate (mg/l) | 0.60±0.03 (0.58-0.64) | 5.37±0.17 (5.21-5.56) | 0.85±0.02 (0.83-0.87) | 0.89±0.02 (0.86-0.91) | 7.13±0.94 (6.21-8.10) | 0.31±0.04 (0.27-0.36) | 0.36±0.02 (0.34-0.39) | 1.07±0.07 (0.99-1.12) |
| 16 | Sodium (mg/l) | 134.00±7.54 (127.00-142.00) | 146.33±3.21 (144.00-150.00) | 189.00±4.35 (186.00-194.00) | 213.66±3.21 (210.00-216.00) | 185.33±4.04 (181.00-189.00) | 187.33±4.93 (184.00-193.00) | 291.00±2.64 (289.00-294.00) | 330.00±4.58 (326.00-335.00) |
| 17 | Potassium (mg/l) | 34.00±5.56 (28.00-39.00) | 31.33±4.93 (28.00-37.00) | 45.33±4.93 (42.00-51.00) | 43.66±3.21 (40.00-46.00) | 40.33±3.05 (37.00-43.00) | 44.66±5.50 (39.00-50.00) | 28.66±1.52 (27.00-30.00) | 23.66±2.51 (21.00-26.00) |
| 18 | Ammonia (mg/l) | 2.35±0.04 (2.31-2.39) | 1.92±0.03 (1.89-1.96) | 1.21±0.04 (1.17-1.25) | 1.15±0.03 (1.12-1.18) | 0.65±0.04 (0.62-0.70) | 0.05±0.01 (0.04-0.06) | 0.07±0.02 (0.05-0.10) | 0.16±0.02 (0.14-0.19) |
| 19 | Iron (mg/l) | 1.47±0.06 (1.40-1.52) | 1.55±0.02 (1.53-1.57) | 0.40±0.03 (0.37-0.43) | 0.58±0.02 (0.56-0.61) | 0.19±0.02 (0.17-0.21) | 0.16±0.02 (0.14-0.19) | 0.04±0.02 (0.03-0.07) | 0.08±0.01 (0.07-0.10) |
| 20 | Sulphate (mg/l) | 25.33±3.05 (22.00-28.00) | 19.66±1.52 (18.00-21.00) | 28.00±6.24 (23.00-35.00) | 23.66±1.52 (22.00-25.00) | 20.33±3.05 (17.00-23.00) | 17.00±2.00 (15.00-19.00) | 21.33±2.51 (19.00-24.00) | 28.00±2.64 (25.00-30.00) |
| 21 | D O (mg/l) | 3.25±0.25 (2.96-3.41) | 3.84±0.10 (3.73-3.92) | 4.76±0.29 (4.56-5.10) | 4.41±0.11 (4.30-4.53) | 4.10±0.16 (3.95-4.27) | 3.01±0.07 (2.95-3.10) | 8.47±0.04 (8.43-8.51) | 6.89±0.06 (6.82-6.94) |
| 22 | B O D (mg/l) | 224.33±2.08 (222.00-226.00) | 114.66±2.08 (113.00-117.00) | 212.66±4.72 (209.00-218.00) | 143.33±3.05 (140.00-146.00) | 110.66±7.09 (103.00-117.00) | 144.33±4.93 (141.00-150.00) | 52.00±2.64 (49.00-54.00) | 102.00±4.00 (98.00-106.00) |
| 23 | C O D (mg/l) | 938.00±16.64 (926.00-957.00) | 1501.33±8.08 (1494.00-1510.00) | 877.00±4.35 (874.00-882.00) | 1765.33±4.16 (1762.00-1770.00) | 2250.00±2.64 (2247.00-2252.000 | 476.33±3.05 (473.00-479.00) | 270.66±8.14 (265.00-280.00) | 403.66±12.74 (389.00-412.00) |

**Table 5.4. Annual Mean values with minimum-maximum ranges of physico-chemical characteristics of Lakshmital Lake**

| Sl. No | Parameters | Mean value ±SD (Range of values in parenthesis) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Site I | Site II | Site III | Site IV | Site V | Site VI | Site VII | Site VIII |
| 1 | Temperature ($^0$C) | 28.06±8.03 (18.10-36.90) | 27.94±8.22 (17.40-37.20) | 27.71±7.86 (17.80-36.60) | 27.51±7.49 (18.00-35.80) | 27.78±7.73 (17.90-36.30) | 27.71±7.99 (17.80-36.90) | 26.53±7.65 (16.60-34.70) | 26.68±7.94 (16.40-35.00) |
| 2 | pH | 7.47±0.79 (6.50-8.60) | 7.23±0.51 (6.60-8.30) | 7.32±0.40 (6.80-8.00) | 7.18±0.41 (6.70-7.90) | 7.51±0.49 (6.90-8.30) | 7.60±0.50 (7.00-8.40) | 7.61±0.45 (7.00-8.30) | 7.03±0.34 (6.50-7.70) |
| 3 | Turbidity (NTU) | 148.77±42.73 (105.00-213.00) | 91.55±35.68 (47.00-139.00) | 60.55±15.96 (37.00-83.00) | 92.88±28.08 (50.00-123.00) | 37.33±9.40 (26.00-52.00) | 56.88±20.09 (29.00-89.00) | 12.88±3.33 (9.00-20.00) | 10.00±1.32 (8.00-12.00) |
| 4 | Elec. Con. (µ mhos/cm) | 902.88±182.17 (734.00-1141.00) | 888.44±183.11 (720.00-1130.00) | 915.22±212.66 (722.00-1195.00) | 976.22±184.07 (810.00-1224.00) | 781.22±183.32 (621.00-1028.00) | 826.66±183.80 (654.00-1070.00) | 677.66±184.75 (508.00-921.00) | 651.66±97.79 (527.00-760.00) |
| 5 | Total suspended solids(mg/l) | 351.33±110.42 (202.00-453.00) | 302.77±60.48 (197.00-369.00) | 295.66±47.86 (217.00-357.00) | 356.00±77.92 (252.00-439.00) | 260.55±52.82 (189.00-321.00) | 255.55±39.38 (205.00-300.00) | 172.88±16.66 (150.00-199.00) | 183.00±25.28 (150.00-220.00) |
| 6 | Total dissolved solids(mg/l) | 743.66±88.77 (628.00-1293.00) | 719.22±79.74 (620.00-816.00) | 690.77±45.83 (635.00-749.00) | 758.77±69.63 (667.00-835.00) | 665.00±48.47 (611.00-732.00) | 662.55±19.85 (643.00-700.00) | 502.44±39.63 (445.00-557.00) | 519.00±43.93 (459.00-574.00) |
| 7 | Total Solids (mg/l) | 1095.00±197.39 (841.00-1293.00) | 1022.00±137.69 (844.00-1181.00) | 986.44±92.16 (866.00-1099.00) | 1114.77±146.89 (922.00-1263.00) | 925.55±99.08 (806.00-1053.00) | 918.11±56.70 (852.00-997.00) | 675.33±54.50 (606.00-749.00) | 702.00±68.43 (615.00-790.00) |
| 8 | Total Hardness (mg/l) | 185.88±22.27 (157.00-218.00) | 190.77±21.26 (170.00-232.00) | 183.33±31.14 (138.00-227.00) | 202.88±25.69 (174.00-240.00) | 187.22±26.88 (157.00-223.00) | 177.11±33.62 (138.00-219.00) | 164.44±33.97 (124.00-219.00) | 302.11±36.46 (263.00-349.00) |
| 9 | Calcium (mg/l) | 82.33±12.39 (64.00-99.00) | 83.44±13.22 (69.00-104.00) | 94.44±16.38 (70.00-116.00) | 91.44±16.01 (68.00-118.00) | 92.77±13.80 (74.00-109.00) | 90.66±11.39 (77.00-110..00) | 82.77±15.80 (61.00-110.00) | 213.11±8.78 (201.00-227.00) |
| 10 | Magnesium (mg/l) | 43.66±12.69 (21.00-63.00) | 50.66±11.66 (33.00-70.00) | 54.33±13.05 (36.00-71.00) | 55.22±13.81 (35.00-76.00) | 56.22±9.92 (40.00-69.00) | 50.88±12.47 (33.00-68.00) | 54.22±10.30 (41.00-68.00) | 120.00±13.17 (103.00-138.00) |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11 | Total alkalinity (mg/l) | 606.11±14.01 (582.00-624.00) | 560.22±28.42 (520.00-587.00) | 680.66±18.64 (649.00-699.00) | 634.33±20.60 (598.00-662.00) | 607.77±23.56 (573.00-632.00) | 593.22±9.48 (581.00-609.00) | 511.77±72.96 (411.00-566.00) | 790.88±26.48 (750.00-812.00) |
| 12 | Chloride (mg/l) | 121.70±42.55 (81.20-183.70) | 105.00±39.13 (64.20-158.30) | 137.58±47.14 (93.90-207.70) | 135.06±48.69 (88.60-208.50) | 150.26±47.34 (105.80-217.00) | 148.20±45.27 (100.50-211.60) | 172.48±57.40 (116.30-250.30) | 200.05±74.30 (137.00-304.60) |
| 13 | Fluoride (mg/l) | 2.09±0.55 (1.22-2.81) | 2.21±0.38 (1.64-2.83) | 2.64±0.32 (2.20-3.12) | 1.65±0.42 (1.03-2.30) | 2.57±0.32 (2.08-3.04) | 1.16±0.28 (0.80-1.76) | 0.90±0.39 (0.30-1.59) | 0.86±0.17 (0.68-1.13) |
| 14 | Phosphate (mg/l) | 1.54±0.26 (1.09-1.81) | 0.65±0.25 (0.24-0.98) | 0.90±0.29 (0.45-1.24) | 1.23±0.15 (1.08-1.47) | 1.07±0.10 (0.86-1.20) | 1.24±0.10 (1.10-1.38) | 0.83±0.30 (0.39-1.11) | 0.43±0.10 (0.29-0.60) |
| 15 | Nitrate (mg/l) | 0.60±0.27 (0.25-0.98) | 6.03±2.56 (3.36-9.97) | 0.83±0.35 (0.36-1.28) | 0.79±0.32 (0.35-1.13) | 8.69±4.53 (4.09-15.36) | 0.39±0.13 (0.25-0.59) | 0.36±0.13 (0.20-0.61) | 1.16±0.44 (0.75-1.75) |
| 16 | Sodium (mg/l) | 102.44±38.40 (48.00-142.00) | 112.66±39.05 (57.00-150.00) | 156.33±38.23 (102.00-194.00) | 173.66±42.62 (108.00-216.00) | 153.44±41.98 (85.0-189.00) | 151.55±43.24 (92.00-193.00) | 251.66±43.15 (177.00-294.00) | 275.00±51.71 (208.00-335.00) |
| 17 | Potassium (mg/l) | 24.44±10.17 (11.00-39.00) | 22.00±9.69 (8.00-37.00) | 37.33±6.89 (29.00-51.00) | 36.55±7.31 (24.00-46.00) | 36.55±5.02 (30.00-43.00) | 34.00±11.01 (16.00-50.00) | 18.55±9.35 (5.00-30.00) | 14.11±8.57 (3.00-26.00) |
| 18 | Ammonia (mg/l) | 2.64±0.94 (1.69-4.03) | 2.18±0.76 (1.43-3.21) | 1.94±0.94 (1.17-3.22) | 1.27±0.50 (0.68-2.01) | 0.72±0.25 (0.44-1.12) | 0.06±0.02 (0.02-0.11) | 0.07±0.03 (0.03-0.15) | 0.16±0.07 (0.03-0.28) |
| 19 | Iron (mg/l) | 2.07±0.50 (1.40-2.72) | 2.09±0.53 (1.53-2.78) | 0.63±0.19 (0.37-0.86) | 0.84±0.20 (0.56-1.08) | 0.24±0.04 (0.17-0.30) | 0.25±0.089 (0.14-0.35) | 0.36±0.46 (0.03-1.02) | 0.12±0.04 (0.07-0.19) |
| 20 | Sulphate (mg/l) | 31.66±13.00 (17.00-52.00) | 27.11±15.07 (13.00-55.00) | 33.66±13.50 (19.00-53.00) | 30.22±13.19 (17.00-52.00) | 27.33±13.22 (15.00-46.00) | 23.77±14.06 (10.00-47.00) | 27.66±12.24 (16.00-45.00) | 37.88±18.08 (20.00-64.00) |
| 21 | D O (mg/l) | 3.04±0.88 (1.67-4.10) | 3.53±0.92 (2.20-4.47) | 4.26±0.79 (2.98-5.10) | 3.98±0.79 (2.89-4.62) | 3.51±1.04 (2.06-4.33) | 3.94±1.60 (2.95-7.61) | 8.27±0.75 (7.30-9.06) | 6.72±0.49 (6.06-7.27) |
| 22 | B O D (mg/l) | 227.22±62.08 (152.00-309.00) | 121.55±30.96 (84.00-165.00) | 225.33±69.30 (146.00-313.00) | 148.11±43.74 (94.00-209.00) | 125.00±43.28 (64.00-187.00) | 153.11±55.16 (84.00-223.00) | 53.11±14.40 (35.00-74.00) | 98.00±20.94 (69.00-123.00) |
| 23 | C O D (mg/l) | 888.88±362.83 (441.00-1288.00) | 1450.77±611.67 (713.00-2145.00) | 833.55±346.95 (410.00-1216.00) | 1707.00±713.66 (849.00-2508.00) | 2107.22±846.70 (1067.00-3160.00) | 663.00±354.49 (369.00-1138.00) | 245.22±95.43 (121.00-344.00) | 362.00±117.75 (208.00-477.00) |

# Correlation coefficient

Correlation coefficients were calculated by Karl Pearson's method, between physico-chemical parameters of Lakshmital to know the interdependence of variables during winter, pre-monsoon, post-monsoon seasons and in annual mean.

## Correlations of variables for winter season

According to **Table 5.5**, during winter season following significant correlations were observed in different variables:

*Temperature*

- significant positive correlation with iron, while
- significant negative relation with total hardness.

*Conductivity*

- significant positive correlation with fluoride, phosphate, potassium and chemical oxygen demand (COD) but
- significant negative correlation with magnesium.

*Total suspended solids (TSS)*

- significant positive correlation with fluoride and iron
- significant negative correlation with calcium

*Calcium*

- significant positive correlation with sulphate
- significant negative correlation with fluoride and phosphate

*Magnesium*

- significant positive correlation with sulphate and dissolved oxygen (DO)
- significant negative correlation with fluoride, phosphate, ammonia and iron

*Phosphate*

- significant positive correlation with potassium and Biochemical oxygen demand
- significant negative correlation with dissolved oxygen

*Total alkalinity*

- significant positive correlation with sulphate

*Total dissolved solids (TDS)*

- significant positive correlation with iron

*Fluoride*

- significant positive correlation with nitrate

*Potassium*

- significant positive correlation with iron;

*pH*

- significant negative correlation with calcium and total alkalinity

*Turbidity*

- significant negative correlation with calcium

*Chloride*

- significant negative correlation with COD;

Rest of the variables did not show any significant correlation in winter season. Studies showed highly significant correlations between magnesium and fluoride [r = (-) 0.509], and between TSS and iron [r = 0.506] during the season.

## Correlations of variables for pre-monsoon season

In pre-monsoon season significant relations between the physico-chemical variables are shown in **Table 5.6,** details of them are as follows:

*Temperature*

- significant positive correlation with fluoride and iron

- significant negative correlation with calcium and magnesium

*pH*

- significant positive correlation with turbidity
- significant negative correlation with sulphate

*Conductivity*

- significant positive correlation with iron,
- significant negative correlation total alkalinity and sulphate

*Total suspended solids*

- significant positive correlation with fluoride
- significant negative correlation with calcium

*Total solids*

- significant positive correlation with fluoride,
- significant negative correlation with total hardness

*Calcium*

- significant positive correlation with dissolved oxygen
- significant negative correlation with potassium and iron

*Total alkalinity*

- significant positive correlation with sodium
- significant negative correlation with phosphate and iron

*Chloride*

- significant positive correlation with sulphate
- significant negative correlation with potassium

*Phosphate*

- significant positive correlation with ammonia
- significant negative correlation with sulphate

*Total alkalinity*

- significant positive correlation with sodium
- significant negative correlation with phosphate and iron

*Turbidity*

- significant negative correlation with calcium and magnesium

*Total hardness*

- significant negative correlation with potassium

*Magnesium*

- significant negative correlation with ammonia and iron

*Nitrate*

- significant negative correlation with ammonia

*Sodium*

- significant negative correlation with potassium

*Potassium*

- significant negative correlation with sulphate

Besides these, no other significant correlations were found during the season. Among all the highest correlation coefficient was recorded between total solids and magnesium; and sodium and potassium [ r = (-) 514] followed by total dissolved solids and calcium
[ r = (-) 511].

## Correlations of variables for post-monsoon season

In the present study during post-monsoon season following significant correlations were obtained **(Table 5.7)**:

*Temperature*

- significant positive correlation with iron and biochemical oxygen demand
- significant negative correlation with turbidity, total suspended solids, total dissolved solids and total solids

*Turbidity*

- significant positive correlation with fluoride
- significant negative correlation with calcium

*Conductivity*

- significant positive correlation with phosphate
- significant negative correlation with calcium

*Total suspended solids*

- significant positive correlation with potassium
- significant negative correlation with calcium

*Total dissolved solids*

- significant positive correlation with potassium
- significant negative correlation with calcium

*Total solids*

- significant positive correlation with potassium
- significant negative correlation with calcium

*Total hardness*

- significant positive correlation with sodium and sulphate
- significant negative correlation with potassium

*Magnesium*

- significant positive correlation with sulphate and dissolved oxygen
- significant negative correlation with fluoride, ammonia and iron

*Fluoride*

- significant positive correlation with iron
- significant negative correlation with dissolved oxygen

*Total alkalinity*

- significant positive correlation with chloride

*Phosphate*

- significant positive correlation with potassium and ammonia

*Potassium*

- significant positive correlation with biochemical oxygen demand

*Iron*

- significant positive correlation with biochemical oxygen demand

*Calcium*

- significant negative correlation with fluoride and potassium

*Chloride*

- significant negative correlation with phosphate

*Sodium*

- significant negative correlation with potassium and chemical oxygen demand

*Dissolved oxygen*

- significant negative correlation with chemical oxygen demand

Rest of the variables did not show any significant correlation. Studies showed highly significant correlations between total dissolved solids and calcium [r = (-) 0.514], and between magnesium and dissolved oxygen [r = (-) 0.513].

## Annual correlations of variables

Details of annual significant correlations in physico-chemical parameters of Lakshmital, shown in **Table 5.8** are as follows:

*Calcium*

- significant positive correlation with dissolved oxygen
- significant negative correlation with ammonia and iron

*Fluoride*

- significant positive correlation with potassium, iron and biochemical oxygen demand
- significant negative correlation with sulphate

*Nitrate*

- significant positive correlation with potassium
- significant negative correlation with dissolved oxygen

*Temperature*

- significant positive correlation with total alkalinity

*pH*

- significant positive correlation with ammonia

*Phosphate*

- significant positive correlation with iron and sulphate

*Turbidity*

- significant negative correlation with sulphate

*Total solids*

- significant negative correlation with chloride

*Magnesium*

- significant negative correlation with ammonia and iron

*Total alkalinity*

- significant negative correlation with iron

*Sulphate*

- significant negative correlation with dissolved oxygen

Besides these, no other annual significant correlations were found. Among all highest correlation coefficient was recorded between fluoride and potassium (r = 300) followed by calcium with iron and nitrate with dissolved oxygen [r = (-) 289].

**Table 5.5. Correlation coefficients for different physico-chemical parameters for Lakshmital Lake during winter season**

| | Temp | pH | Turb. | Cond. | TSS | TDS | TS | THard | $Ca^{2+}$ | $Mg^{2+}$ | T.Alk. | $Cl^-$ | $F^-$ | $PO_4^{2+}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $NH_3$ | Fe | $SO_4^{2-}$ | DO | BOD | COD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| pH | -.058 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| Turb. | .651 | .121 | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Cond. | .645 | -.182 | .860 | 1.000 | | | | | | | | | | | | | | | | | | | |
| TSS | .641 | -.108 | .672 | .882 | 1.000 | | | | | | | | | | | | | | | | | | |
| TDS | .866 | .002 | .745 | .844 | .825 | 1.000 | | | | | | | | | | | | | | | | | |
| TS | .824 | -.036 | .751 | .892 | .919 | .981 | 1.000 | | | | | | | | | | | | | | | | |
| T.Hard | -.455* | -.566 | -.298 | -.093 | -.258 | -.382 | -.355 | 1.000 | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | -.598 | -.424* | -.487* | -.362 | -.495* | -.591 | -.582 | .925 | 1.000 | | | | | | | | | | | | | | |
| $Mg^{2+}$ | -.633 | -.440 | -.586 | -.432* | -.540 | -.614 | -.613 | .881 | .967 | 1.000 | | | | | | | | | | | | | |
| T. Alk. | -.045 | -.477* | .020 | .241 | .081 | .073 | .079 | .786 | .723 | .654 | 1.000 | | | | | | | | | | | | |
| $Cl^-$ | -.697 | -.045 | -.732 | -.701 | -.670 | -.737 | -.744 | .558 | .685 | .715 | .276 | 1.000 | | | | | | | | | | | |
| $F^-$ | .644 | .020 | .457 | .475* | .484* | .613 | .594 | -.360 | -.460* | -.509* | .002 | -.639 | 1.000 | | | | | | | | | | |
| $PO_4^{2+}$ | .596 | .321 | .632 | .444* | .383 | .624 | .567 | -.370 | -.440* | -.473* | -.011 | -.243 | .182 | 1.000 | | | | | | | | | |
| $NO_3$ | .271 | .040 | -.246 | -.248 | -.081 | .119 | .055 | -.137 | -.101 | -.035 | -.056 | .102 | .411* | .189 | 1.000 | | | | | | | | |
| $Na^+$ | -.827 | -.129 | -.763 | -.684 | -. 659 | -.851 | -.820 | .509 | .648 | .699 | .128 | .874 | -.674 | -.516 | -.152 | 1.000 | | | | | | | |
| $K^+$ | .639 | -.056 | .252 | .445* | .626 | .676 | .687 | -.255 | -.388 | -.394 | .136 | -.202 | .461* | .461* | .415* | -.385 | 1.000 | | | | | | |
| $NH_3$ | .526 | -.031 | .758 | .707 | .604 | .551 | .592 | -.212 | -.365 | -.476* | .054 | -.792 | .709 | .101 | -.136 | -.717 | .154 | 1.000 | | | | | |
| Fe | .441* | .005 | .808 | .669 | .506* | .495* | .519 | -.222 | -.376 | -.465* | -.106 | -.825 | .461* | .187 | -.234 | -.741 | -.118 | .870 | 1.000 | | | | |
| $SO_4^{2-}$ | -.226 | -.193 | .006 | .046 | -.047 | -.269 | -.203 | .542 | .474* | .409* | .487* | .300 | -.036 | -.238 | -.179 | .303 | -.098 | .233 | .010 | 1.000 | | | |
| DO | -.769 | .103 | -.735 | -.768 | -.704 | -.843 | -.830 | .138 | .337 | .414* | -.250 | .676 | -.733 | -.499* | -.280 | .833 | -.544 | -.701 | -.626 | .071 | 1.000 | | |
| BOD | .561 | .026 | .757 | .726 | .618 | .654 | .669 | -.108 | -.237 | -.365 | .386 | -.531 | .600 | .436* | -.134 | -.654 | .395 | .780 | .570 | .266 | -.697 | 1.000 | |
| COD | .641 | -.177 | .313 | .451* | .529 | .646 | .632 | -.187 | -.360 | -.306 | -.009 | -.407* | .576 | .399 | .694 | -.543 | .597 | .265 | .248 | -.225 | -.700 | .156 | 1.000 |

* Correlation is significant at the 0.05 level (2-tailed).

N = 24

**Table 5.6. Correlation coefficients for different physico-chemical parameters for Lakshmital Lake during pre-monsoon season**

| | Temp | pH | Turb. | Cond. | TSS | TDS | TS | THard | $Ca^{2+}$ | $Mg^{2+}$ | T.Alk. | $Cl^-$ | $F^-$ | $PO_4^{2+}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $NH_3$ | Fe | $SO_4^{2-}$ | DO | BOD | COD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| pH | .239 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| Turb. | .618 | .467* | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Cond. | .545 | .261 | .671 | 1.000 | | | | | | | | | | | | | | | | | | | |
| TSS | .548 | .241 | .854 | .823 | 1.000 | | | | | | | | | | | | | | | | | | |
| TDS | .615 | .205 | .805 | .891 | .960 | 1.000 | | | | | | | | | | | | | | | | | |
| TS | .592 | .223 | .834 | .870 | .987 | .992 | 1.000 | | | | | | | | | | | | | | | | |
| T.Hard | -.287 | -.502 | -.368 | -.713 | -.378 | -.429* | -.411* | 1.000 | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | -.439* | -.554 | -.468* | -.733 | -.465* | -.511* | -.496* | .906 | 1.000 | | | | | | | | | | | | | | |
| $Mg^{2+}$ | -.479* | -.607 | -.507* | -.743 | -.488 | -.525 | -.514* | .894 | .982 | 1.000 | | | | | | | | | | | | | |
| T. Alk. | -.265 | -.562 | -.287 | -.417* | -.193 | -.220 | -.210 | .753 | .891 | .862 | 1.000 | | | | | | | | | | | | |
| $Cl^-$ | -.740 | -.360 | -.736 | -.871 | -.746 | -.812 | -.791 | .727 | .800 | .808 | .618 | 1.000 | | | | | | | | | | | |
| $F^-$ | .423* | .127 | .322 | 571 | .447* | .532 | .500* | -.364 | -.318 | -.359 | -.033 | -.529 | 1.000 | | | | | | | | | | |
| $PO_4^{2+}$ | .358 | .579 | .685 | .693 | .726 | .663 | .698 | -.600 | -.679 | -.707 | -.461* | -.578 | .173 | 1.000 | | | | | | | | | |
| $NO_3$ | .098 | .147 | -.175 | -.072 | -.072 | -.019 | -.042 | -.073 | -.119 | -.141 | -.088 | -.035 | .524 | -.053 | 1.000 | | | | | | | | |
| $Na^+$ | -.856 | -.394 | -.811 | -.806 | -.794 | -.845 | -.831 | .558 | .659 | .701 | .446* | .935 | -.595 | -.620 | -.121 | 1.000 | | | | | | | |
| $K^+$ | .331 | .281 | .201 | .677 | .519 | .592 | .566 | -.479* | -.505* | -.539 | -.244 | -.492* | .560 | .564 | .377 | -.514* | 1.000 | | | | | | |
| $NH_3$ | .600 | .143 | .825 | .714 | .759 | .745 | .758 | -.386 | -.396 | -.416* | -.128 | -.740 | .596 | .433* | -.133* | -.768 | .182 | 1.000 | | | | | |
| Fe | .509* | .240 | .789 | .466* | .582 | .526 | .556 | -.349 | -.458* | -.455* | -.461* | -.702 | .176 | .328 | -.278 | -.653 | -.158 | .782 | 1.000 | | | | |
| $SO_4^{2-}$ | -.250 | -.506* | -.151 | -.437* | -.192 | -.250 | -.227 | .632 | .770 | .766 | .794 | .503* | -.104 | -.466* | -.197 | .400 | -.494* | .007 | -.153 | 1.000 | | | |
| DO | -.789 | -.281 | -.687 | -.745 | -.780 | -.867 | -.837 | .390 | .476* | .518 | .211 | .794 | -.698 | -.539 | -.332 | .915 | -.640 | -.638 | -.386 | .273 | 1.000 | | |
| BOD | .616 | .252 | .650 | .708 | .702 | .707 | .712 | -.370 | -.325 | -.382 | .067 | -.566 | .533 | .655 | -.093 | -.707 | .527 | .701 | .257 | -.039 | -.705 | 1.000 | |
| COD | .391 | .072 | .302 | .545 | .548 | .648 | .610 | -.301 | -.392 | -.400 | -.223 | -.558 | .674 | .246 | .663 | -.565 | .647 | .314 | .129 | -.312 | -.749 | .209 | 1.000 |

* Correlation is significant at the 0.05 level (2-tailed).
N = 24

**Table 5.7. Correlation coefficient for different physico-chemical parameters for Lakshmital Lake during post-monsoon season**

| | Temp | pH | Turb. | Cond. | TSS | TDS | TS | THard | $Ca^{2+}$ | $Mg^{2+}$ | T.Alk. | $Cl^-$ | $F^-$ | $PO_4^{2+}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $NH_3$ | Fe | $SO_4^{2-}$ | DO | BOD | COD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| pH | -.286 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| Turb. | .575 | -.501* | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Cond. | .608 | -.390 | .791 | 1.000 | | | | | | | | | | | | | | | | | | | |
| TSS | .669 | -.479* | .901 | .943 | 1.000 | | | | | | | | | | | | | | | | | | |
| TDS | .679 | -.429* | .880 | .932 | .972 | 1.000 | | | | | | | | | | | | | | | | | |
| TS | .679 | -.455* | .896 | .944 | .992 | .994 | 1.000 | | | | | | | | | | | | | | | | |
| T.Hard | -.105 | -.361 | -.184 | -.159 | -.149 | -.181 | -.167 | 1.000 | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | -.375 | -.108 | -.478* | -483* | -.486* | -.514* | -.505* | .900 | 1.000 | | | | | | | | | | | | | | |
| $Mg^{2+}$ | -.353 | -.056 | -.570 | -.567 | -.577 | -.598 | -.593 | .850 | .954 | 1.000 | | | | | | | | | | | | | |
| T. Alk. | -.164 | -.202 | -.355 | -.202 | -.236 | -.297 | -.271 | .879 | .880 | .851 | 1.000 | | | | | | | | | | | | |
| $Cl^-$ | -.571 | .340 | -.840 | -.844 | -.861 | -.915 | -.897 | .300 | .632 | .684 | .466* | 1.000 | | | | | | | | | | | |
| $F^-$ | .522 | -.265 | .469* | .581 | .641 | .700 | .678 | -.230 | -.472* | -.500* | -.197 | -.672 | 1.000 | | | | | | | | | | |
| $PO_4^{2+}$ | .386 | -.208 | .644 | . 480* | .623 | .530 | .577 | -.587 | -.656 | -.723 | -.539 | -.406* | .283 | 1.000 | | | | | | | | | |
| $NO_3$ | .241 | .198 | -.209 | -.145 | -.023 | .059 | .022 | -.112 | -.102 | -.058 | -.122 | .022 | .380 | .037 | 1.000 | | | | | | | | |
| $Na^+$ | -.642 | .255 | -.811 | -.744 | -.812 | -.876 | -.853 | .466* | .683 | .772 | .544 | .853 | -.724 | -.620 | -.168 | 1.000 | | | | | | | |
| $K^+$ | .370 | .105 | .220 | .583 | .471* | .473* | .476* | -.468* | -.481* | -.529 | -.239 | -.310 | .397 | .458* | .160 | -.486* | 1.000 | | | | | | |
| $NH_4^+$ | .569 | -.560 | .895 | .719 | .840 | .853 | .853 | -.049 | -.399 | -.440* | -.207 | -.864 | .669 | .409* | -.104 | -.748 | .074 | 1.000 | | | | | |
| Fe | .479* | -.517 | .891 | .616 | .727 | .773 | .757 | -.043 | -.357 | -.410* | -.313 | -.840 | .488* | .313 | -.201 | -.715 | -.076 | .936 | 1.000 | | | | |
| $SO_4^{2-}$ | -.059 | -.145 | .016 | .028 | .056 | -.040 | .004 | .486* | .401 | .414* | .629 | .129 | .103 | -.188 | -.236 | .267 | -.101 | .185 | .008 | 1.000 | | | |
| DO | -.630 | .249 | -.713 | -.740 | -.772 | -.816 | -.801 | 189 | .366 | .513* | .256 | .658 | -.507* | -.536 | -.174 | .866 | -.556 | -.539 | -.526 | .271 | 1.000 | | |
| BOD | .500* | -.405* | .678 | .695 | .744 | .675 | .711 | -.041 | -.228 | -.349 | .113 | -.499 | .556 | .560 | -.203 | -.631 | .465* | .643 | .458* | .344 | -.655 | 1.000 | |
| COD | .540 | -.117 | .307 | .519 | .561 | .637 | .607 | -.073 | -.330 | -.314 | -.207 | -.570 | .624 | .158 | .700 | -.504* | .355 | .399 | .289 | -.157 | -.482* | .085 | 1.000 |

* Correlation is significant at the 0.05 level (2-tailed)

N = 24

**Table 5.8. Annual correlation coefficients for different physico-chemical parameters for Lakshmital Lake**

| | Temp | pH | Turb. | Cond. | TSS | TDS | TS | THard | $Ca^{2+}$ | $Mg^{2+}$ | T.Alk. | $Cl^-$ | $F^-$ | $PO_4^{2+}$ | $NO_3^-$ | $Na^+$ | $K^+$ | $NH_3$ | Fe | $SO_4^{2-}$ | DO | BOD | COD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1.000 | | | | | | | | | | | | | | | | | | | | | | |
| pH | .663 | 1.000 | | | | | | | | | | | | | | | | | | | | | |
| Turb. | -.047 | -.204 | 1.000 | | | | | | | | | | | | | | | | | | | | |
| Cond. | .542 | .558 | .111 | 1.000 | | | | | | | | | | | | | | | | | | | |
| TSS | .461 | .099 | .714 | .359 | 1.000 | | | | | | | | | | | | | | | | | | |
| TDS | .339 | .032 | .761 | .354 | .938 | 1.000 | | | | | | | | | | | | | | | | | |
| TS | .399 | .063 | .751 | .362 | .981 | .987 | 1.000 | | | | | | | | | | | | | | | | |
| T.Hard | .201 | .018 | -.370 | .187 | -.254 | -.349 | -.311 | 1.000 | | | | | | | | | | | | | | | |
| $Ca^{2+}$ | .094 | -.066 | -.509 | -.079 | -.394 | -.498 | -.459 | .891 | 1.000 | | | | | | | | | | | | | | |
| $Mg^{2+}$ | .096 | -.007 | -.602 | .019 | -.476 | -.565 | -.534 | .895 | .954 | 1.000 | | | | | | | | | | | | | |
| T. Alk. | .259* | -.112 | -.172 | .002 | .045 | -.012 | .014 | .683 | .770 | .671 | 1.000 | | | | | | | | | | | | |
| $Cl^-$ | .714 | .579 | -.536 | .380 | -.156 | -.305 | -.242* | .602 | .541 | .605 | .397 | 1.000 | | | | | | | | | | | |
| $F^-$ | -.206 | -.202 | .416 | .112 | .307 | .464 | .400 | -.359 | -.439 | -.462 | -.120 | -.503 | 1.000 | | | | | | | | | | |
| $PO_4^{2+}$ | .483 | .442 | .490 | .493 | .625 | .609 | .626 | -.314 | -.451 | -.458 | -.135 | .126 | .068 | 1.000 | | | | | | | | | |
| $NO_3^-$ | .143 | .190 | -.191 | .013 | .002 | .056 | .032 | -.043 | -.077 | -.052 | -.047 | .105 | .367 | .083 | 1.000 | | | | | | | | |
| $Na^+$ | .401 | .141 | -.542 | -.315 | -.191 | -.375 | -.297 | .333 | .517 | .476 | .442 | .595 | -.618 | -.216 | -.061 | 1.000 | | | | | | | |
| $K^+$ | .418 | .167 | .277 | .157 | .654 | .678 | .678 | -.379 | -.398 | -.474 | .094 | -.029 | .300* | .535 | .275* | .030 | 1.000 | | | | | | |
| $NH_3$ | .374 | .235* | .544 | .646 | .632 | .621 | .636 | -.068 | -.245* | -.239* | -.008 | -.078 | .437 | .414 | -.070 | -.440 | .153 | 1.000 | | | | | |
| $Fe^{2+}$ | .171 | .175 | .572 | .526 | .404 | .427 | .424 | -.065 | -.289* | -.266* | -.249* | -.189 | .271* | .283* | -.208 | -.556 | -.158 | .806 | 1.000 | | | | |
| $SO_4^{2-}$ | .794 | .603 | -.242* | .663 | .136 | -.001 | .061 | .564 | .415 | .483 | .400 | .858 | -.245* | .246* | .039 | .321 | .026 | .367 | .193 | 1.000 | | | |
| DO | -.440 | -.305 | -.514 | -.656 | -.665 | -.746 | -.721 | .067 | .269* | .303 | -.046 | .014 | -.470 | -.597 | -.289* | .522 | -.514 | -.651 | -.509 | -.285* | 1.000 | | |
| BOD | .584 | .419 | .384 | .695 | .647 | .601 | .631 | .020 | -.105 | -.140 | .259* | .217 | .271* | .647 | -.034 | -.231 | .443 | .735 | .390 | . 533 | -.729 | 1.000 | |
| COD | .547 | .345 | .156 | .540 | .580 | .603 | .602 | -.017 | -.199 | -.170 | .009 | .157 | .338 | .400 | .640 | -.131 | .510 | .436 | .223 | 353 | -.680 | .401 | 1.000 |

* Correlation is significant at the 0.05 level (2-tailed).

N = 72

# (B) Metal Analysis

Trace elements, and especially so-called heavy metals, are among the most common environmental pollutants, and their occurrence in waters, sediments and biota indicates the presence of natural or anthropogenic sources (Forstner *et al.,* 1979). Metal concentrations in the water column and the sediments of a water body determine the quality of water (Saikia *et al.*, 1988). However, concentrations of metals and their impacts can be greatly modified due to interaction with natural water ingredients (Pettersen *et al.*, 1993). Therefore, knowledge of the concentrations of trace elements is desirable for the estimation of pollution levels of waters and the determination of background values of metal concentrations in corresponding regions. In the present study six metals (Cd, Cr, Cu, Mn, Ni, Pb, and Zn) were analysed in the water samples, sediment samples and in the macrophytes of Lakshmital Lake. The results of metal analysis in the current study are as follows:

## Metals concentration in water

### Cadmium

Variation in cadmium (Cd in mg/l) concentration at different locations of Lakshmital has been shown by **Figure 5.24.** Cadmium at different sites varied between 0.001 and 0.06 mg/l with an average mean of 0.015 mg/l. Site I exhibited the maximum cadmium concentration (0.06 mg/l) followed by site II (0.02 mg/l) while site III and VI showed the minimum value (0.001 mg/l) as depicted by **Table 5.9**.

### Chromium

Variation in chromium (Cr in mg/l) contents at different sites of Lakshmital has been represented by **Figure 5.25**. At different locations chromium varied between 0.018 and 0.220 mg/l with an average mean value of 0.093 mg/l. Site I exhibited the maximum value (0.220 mg/l) followed by site II (0.140 mg/l) and site V (0.100 mg/l). Minimum concentration was observed at site IV (0.018 mg/l) (**Table 5.9**).

### Copper

**Figure 5.26** exhibits the variation in copper (Cu in mg/l) concentration at different locations of Lakshmital. According to **Table 5.9**, copper at different sites varied from 0.11 to 0.69 mg/l at site I and site VI respectively with an average mean of 0.343 mg/l. Site I with highest concentration (0.69 mg/l) is followed by site II (0.50 mg/l) and site V (0.37 mg/l) while Site VI exhibited the lowest concentration of copper.

### Manganese

Variation in manganese (Mn in mg/l) concentration at different locations of Lakshmital has been shown by **Figure 5.27.** Manganese at different sites varied between 0.20 and 0.79 mg/l with an average mean of 0.431 mg/l. Site I exhibited the maximum manganese concentration (0.79 mg/l) followed by site II (0.58 mg/l) while site VI showed the minimum value (0.20 mg/l) as depicted by **Table 5.9**.

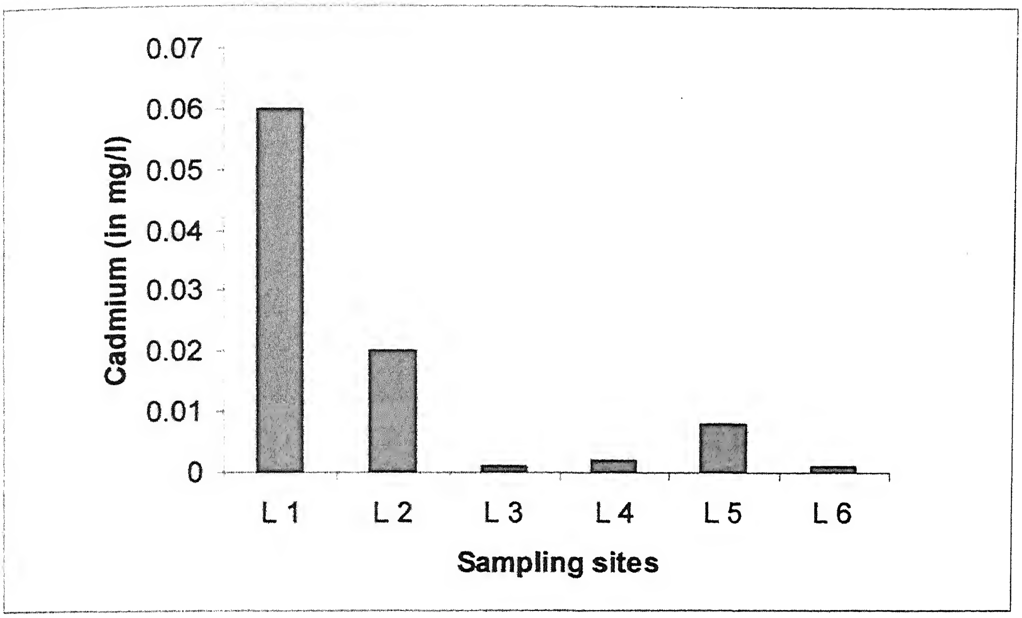



**Figure 5.24. Variation in cadmium concentration (in mg/l) in water at different locations of Lakshmital**

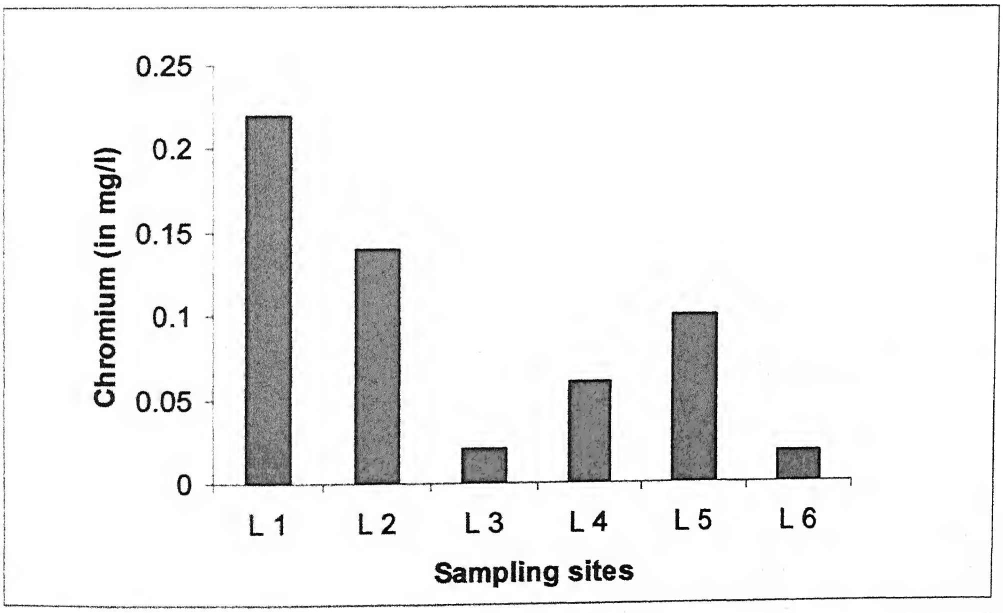



**Figure 5.25. Variation in chromium concentration (in mg/l) in water at different locations of Lakshmital**

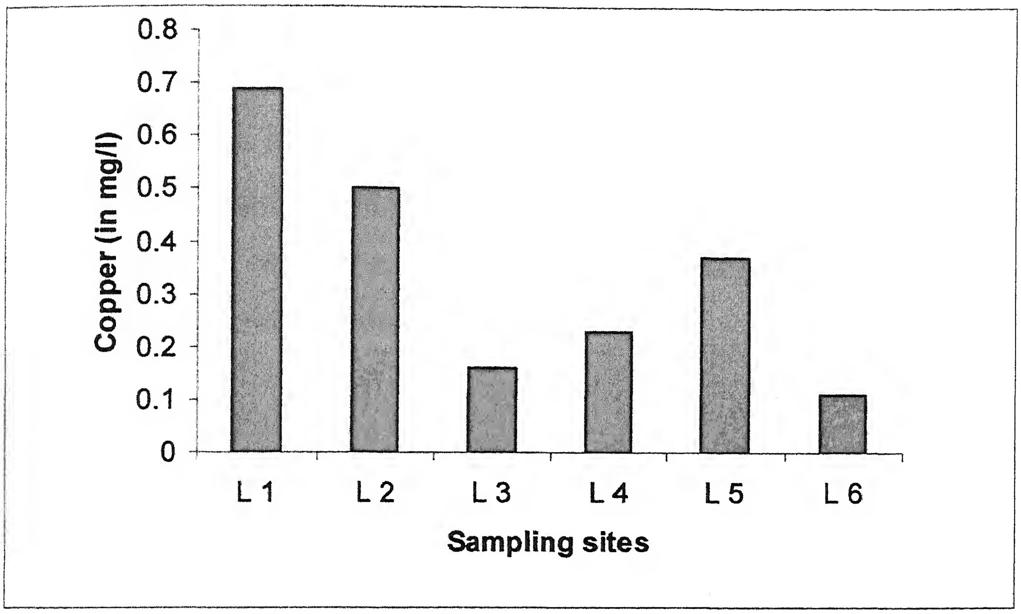



**Figure 5.26. Variation in copper concentration (in mg/l) in water at different locations of Lakshmital**

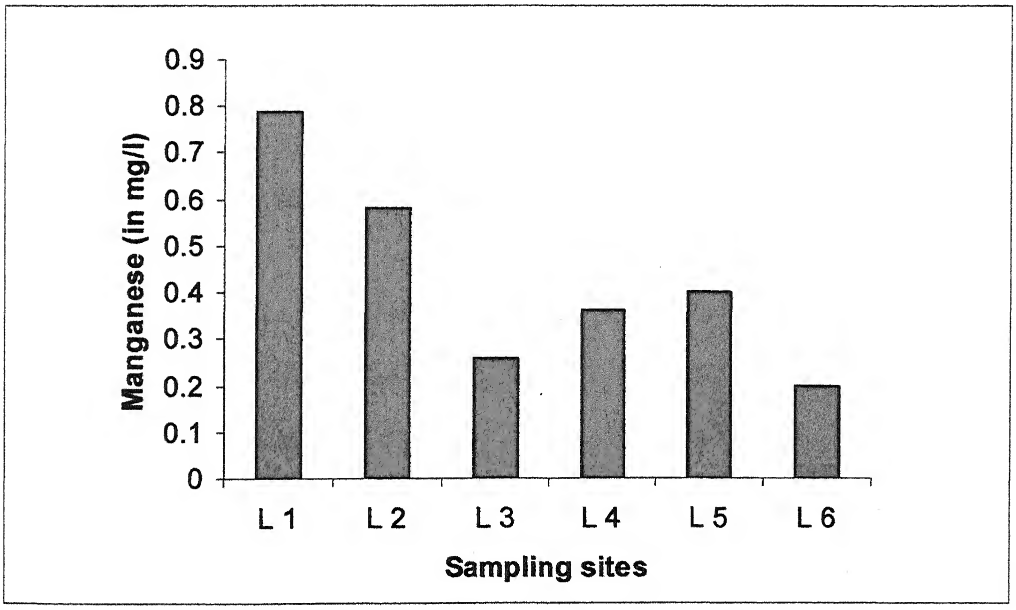



**Figure 5.27. Variation in manganese concentration (in mg/l) in water at different locations of Lakshmital**

## Nickel

Variation in nickel (Ni in mg/l) contents at different sites of Lakshmital has been represented by **Figure 5.28.** Nickel was observed only at site I and site II with low concentration values i.e. 0.009 mg/l and 0.002 mg/l and at rest of the sites it was below detectable limits (**Table 5.9**).

## Lead

Variation in lead (Pb in mg/l) concentration at different locations of Lakshmital has been shown by **Figure 5.29.** Lead at different sites varied between 0.001 and 0.020 mg/l with an average mean of 0.005 mg/l. Site I exhibited the maximum lead concentration (0.020 mg/l) followed by site II (0.009 mg/l) while site IV showed the minimum value (0.001 mg/l). At site III and site VI it was observed below detectable limits **(Table 5.9).**

## Zinc

Variation in zinc (Zn in mg/l) concentration at different locations of Lakshmital has been shown by **Figure 5.30.** Zinc at different sites varied between 0.17 and 0.77 mg/l with an average mean of 0.41 mg/l. Site I exhibited the maximum zinc concentration (0.77 mg/l) followed by site II (0.56 mg/l) while site VI showed the minimum value (0.17 mg/l) as depicted by **Table 5.9**.

According to **Figure 5.31**, mean metal's concentrations of all sites varied from 0.001 to 0.430 mg/l that followed the order of Pb < Cd < Cr < Cu < Zn < Mn.

**Table 5.9. Mean values with minimum-maximum ranges of metals in water samples of Lakshmital Lake**

| S.No. | Heavy metals | Mean value ±S D ( Range of values in parenthesis) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Site I | Site II | Site III | Site IV | Site V | Site VI |
| 1 | Cadmium | 0.06±0.01 (0.04-0.08) | 0.020±0.008 (0.020-0.040) | 0.001±.001 (0.000-0.003) | 0.002±0.001 (0.001-0.004) | 0.008±0.001 (0.007-0.010) | 0.001±0.000 (0.000-0.002) |
| 2 | Chromium | 0.22±0.01 (0.21-0.25) | 0.14±0.01 (0.13-0.17) | 0.020±0.008 (0.020-0.040) | 0.060±0.008 (0.060-0.080) | 0.10±0.01 (0.09-0.12) | 0.018±0.008 (0.010-0.030) |
| 3 | Copper | 0.69±0.01 (0.67-0.72) | 0.50±0.01 (0.48-0.52) | 0.16±0.02 (0.14-0.19) | 0.23±0.02 (0.20-0.26) | 0.37±0.03 (0.34-0.42) | 0.11±0.01 (0.10-0.13) |
| 4 | Manganese | 0.79±0.04 (0.72-0.85) | 0.58±0.03 (0.54-0.63) | 0.26±0.02 (0.23-0.28) | 0.36±0.01 (0.34-0.39) | 0.40±0.02 (0.37-0.43) | 0.20-0.02 (0.17-0.24) |
| 5 | Nickel | 0.009±0.000 (0.009-0.010) | 0.002±0.000 (0.002-0.003) | 0.00±0.00 (0.00-0.00) | 0.000±0.000 (0.000-0.001) | 0.000±0.000 (0.000-0.001) | 0.00±0.00 (0.00-0.00) |

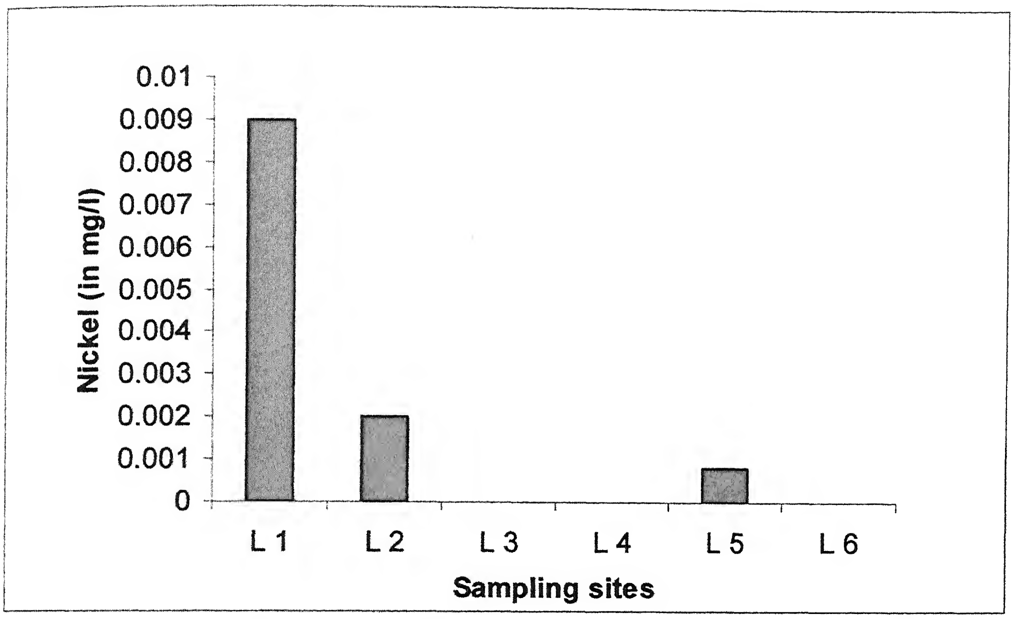



**Figure 5.28. Variation in nickel concentration (in mg/l) in water at different locations of Lakshmital**

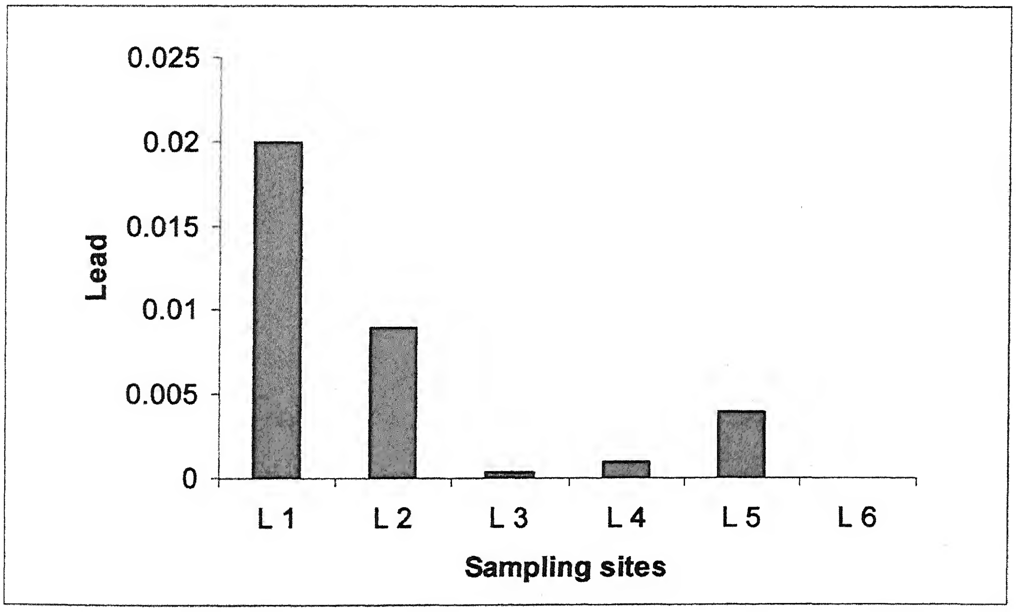



**Figure 5.29. Variation in Lead concentration (in mg/l) in water at different locations of Lakshmital**

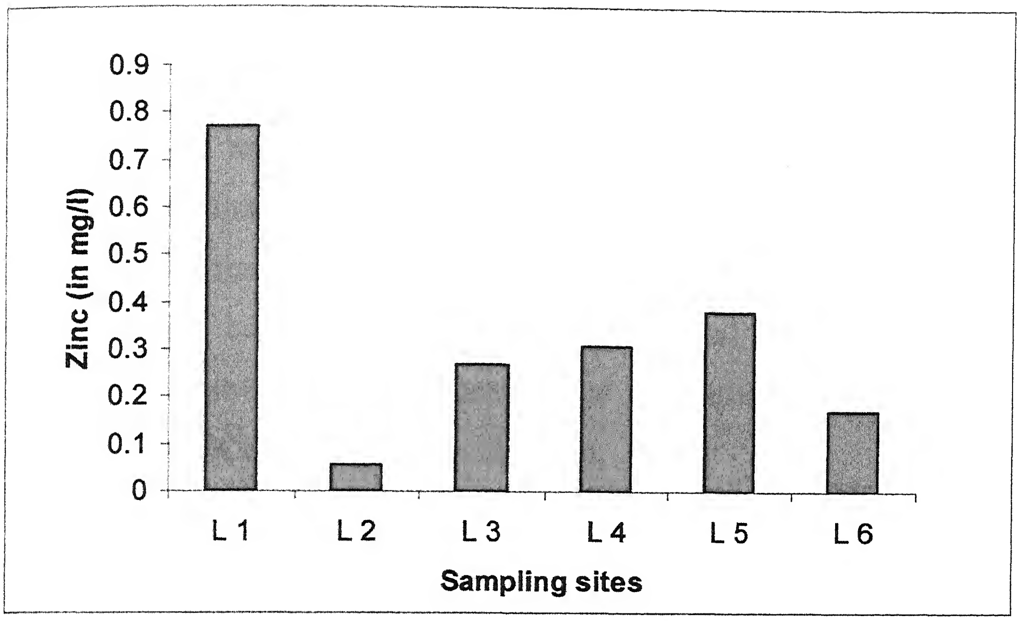



**Figure 5.30. Variation in Zinc concentration (in mg/l) in water at different locations of Lakshmital**

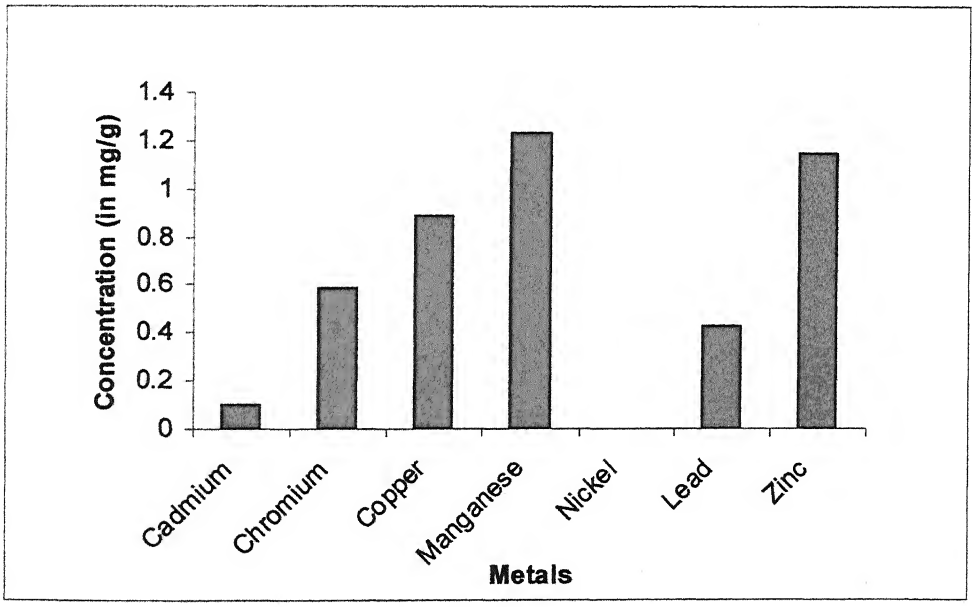



**Figure 5.31. Variation in mean metals concentration (in mg/l) in water at all locations of Lakshmital**

## Metals concentration in sediments

Metal concentration in sediments collected from Lakshmital is shown by **Figure 5.32**. Mean manganese was observed in highest concentration (1.23 mg/g) followed by zinc (1.15 mg/g) and copper (0.89 mg/g) while cadmium showed the lowest concentration (0.10 mg/g). Nickel was found below detectable limits (**Table 5.10**). All mean metal concentrations in sediments followed the order of Cd< Pb< Cr< Cu< Zn< Mn.

**Table 5.10. Metal concentration in sediment samples collected from Lakshmital Lake**

| Sl. No. | Metals (in mg/g) | Range | Mean ± SD |
|---|---|---|---|
| 1 | Cadmium | 0.090- 0.110 | 0.100±0.007 |
| 2 | Chromium | 0.530-0.650 | 0.590±0.050 |
| 3 | Copper | 0.820-1.000 | 0.890±0.070 |
| 4 | Manganese | 1.130-1.300 | 1.230±0.060 |
| 5 | Nickel | 0.000-0.002 | 0.000±0.000 |
| 6 | Lead | 0.390-0.460 | 0.430±0.020 |
| 7 | Zinc | 1.030-1.320 | 1.150±0.110 |

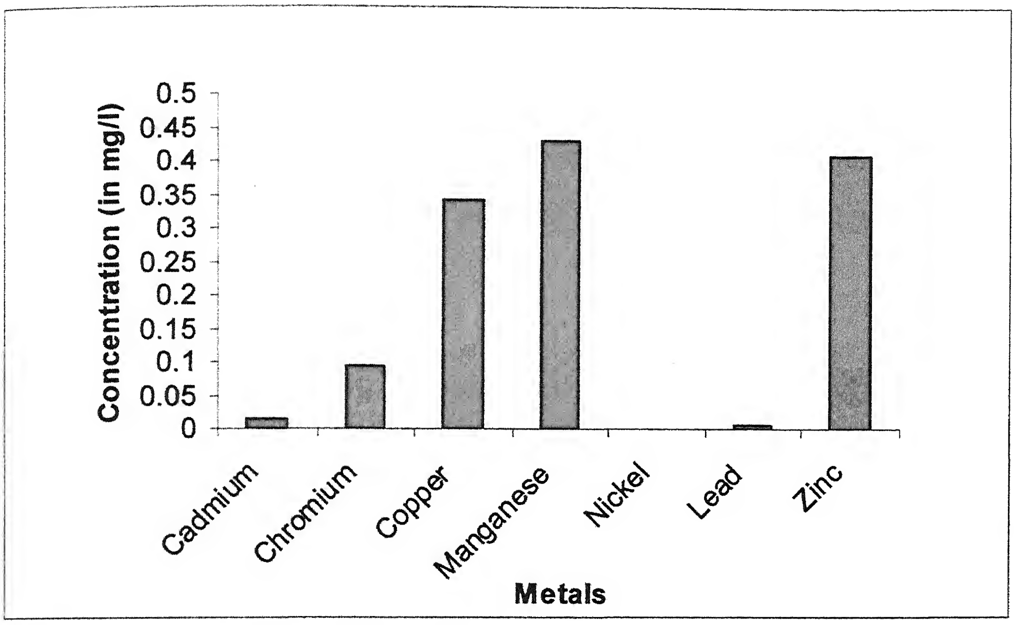



**Figure 5.32. Variation in mean metal concentration (in mg/g) in sediments of Lakshmital**

## Metal concentration in plants

Metals (Cd, Cr, Cu, Mn, Ni, Pb, and Zn) concentration in plants collected from Lakshmital is shown in **Table 5.11**. A detailed description of obtained results is as follows:

### *Phalaris arundinacea*

In *P. arundinacea* roots metal concentration varied between 0.001 mg/g (Zn) and 0.004 mg/g (Cu and Mn). Nickel was below detectable limits. Metal concentration in leaves varied from 0.001 mg/g (Cr and Cu) to 0.003 mg/g (Zn) while cadmium and lead was exhibited below detectable limits (**Figure 5.33**). The total metal concentration in the species was found in order of Cd and Pb<Cr, Cu and Zn< Mn.

### *Eichhornia crassipes*

In *E. crassipes* roots metal concentration was observed in the range of 0.001 mg/g (Cd) to 0.008 mg/g (Cu and Mn). Nickel was found below detectable limits. In its leaves metal accumulation varied between 0.001 (Cr and Pb) to 0.005 (Mn). Cadmium and nickel was below detectable limits as shown in **Figure 5.34**. The order of different metals accumulation in the plant was found Cr and Pb<Zn<Cu<Mn.

### *Potamogeton zosteriformis*

In *P. zosteriformis* roots metal concentration varied between 0.001 mg/g (Pb) and 0.030 mg/g (Zn). Cadmium and nickel was below detectable limits. Metal concentration in leaves varied from 0.001 mg/g (Mn) to 0.008 mg/g (Zn) while

cadmium, chromium, nickel and lead were below detectable limits (**Figure 5.35**). The total metal concentration in the species was found in order of Cr<Mn< Cu< Zn.

***Elatine triandra***

In *E. triandra* roots metal concentration was observed in the range of 0.001 mg/g (Cd and Ni) to 0.008 mg/g (Zn). In the leaves metal concentration varied between 0.001 (Cr and Pb) to 0.006 (Zn). Cadmium and nickel was below detectable limits as shown in **Figure 5.36**. The order of different metals concentration in the plant was found Cr< Pb<Cu and Mn<Zn.

According to **Figure 5.37**, it was depicted that the highest metals accumulation was found in *P. zosteriformis* roots (0.007 mg/g) while *P. arundinacea* leaves, *P. zosteriformis* leaves and *E. triandra* leaves accumulated the lowest metal contents (0.001 mg/g). In all four species *P. zosteriformis* accumulated the maximum metal contents (0.004 mg/g) and *P. arundinacea* accumulated the lowest amount of metals (0.001 mg/g) as shown in **Figure 5.38**.

**Table 5.11. Variation in metal concentration (in mg/g) in roots and leaves of aquatic plant species collected from Lakshmital Lake**

| Species | Plant parts | Metals (in mg/g) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Cadmium | Chromium | Copper | Manganese | Nickel | Lead | Zinc |
| *Phalaris arundinacea* | Root | 0.002 | 0.003 | 0.004 | 0.004 | 0.000 | 0.002 | 0.001 |
| | Leaf | 0.000 | 0.001 | 0.001 | 0.002 | 0.001 | 0.000 | 0.003 |
| *Eichhornia crassipes* | Root | 0.001 | 0.002 | 0.008 | 0.008 | 0.000 | 0.002 | 0.004 |
| | Leaf | 0.000 | 0.001 | 0.003 | 0.005 | 0.000 | 0.001 | 0.004 |
| *Potamogeton zosteriformis* | Root | 0.000 | 0.002 | 0.010 | 0.006 | 0.000 | 0.001 | 0.030 |
| | Leaf | 0.000 | 0.000 | 0.004 | 0.001 | 0.000 | 0.000 | 0.008 |
| *Elatine triandra* | Root | 0.001 | 0.002 | 0.005 | 0.005 | 0.001 | 0.004 | 0.008 |
| | Leaf | 0.000 | 0.001 | 0.002 | 0.002 | 0.000 | 0.001 | 0.006 |

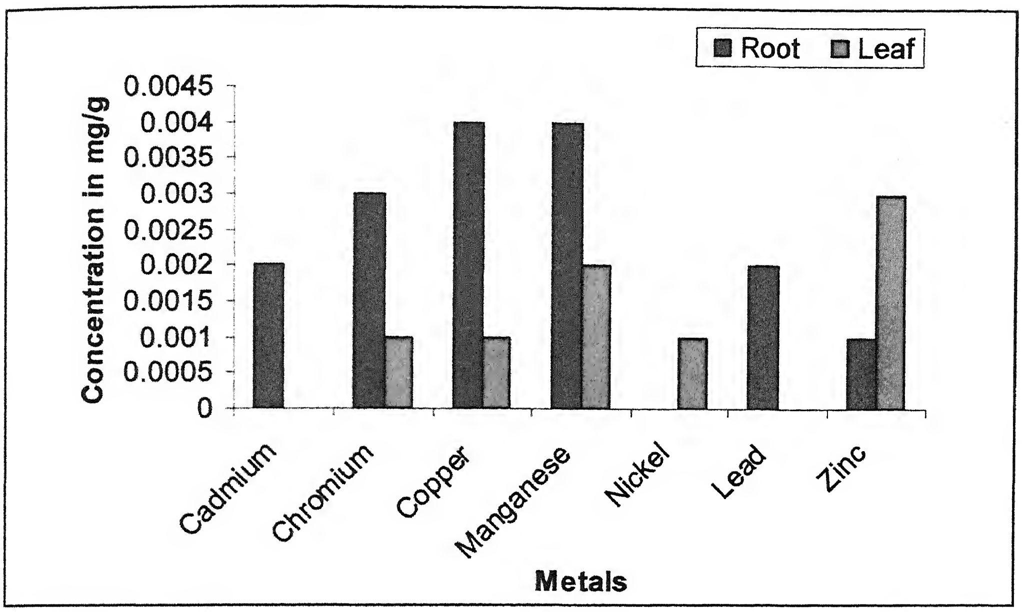



**Figure 5.33. Metal concentration (in mg/g) in roots and leaves of *Phalaris arundinacea* collected from Lakshmital**

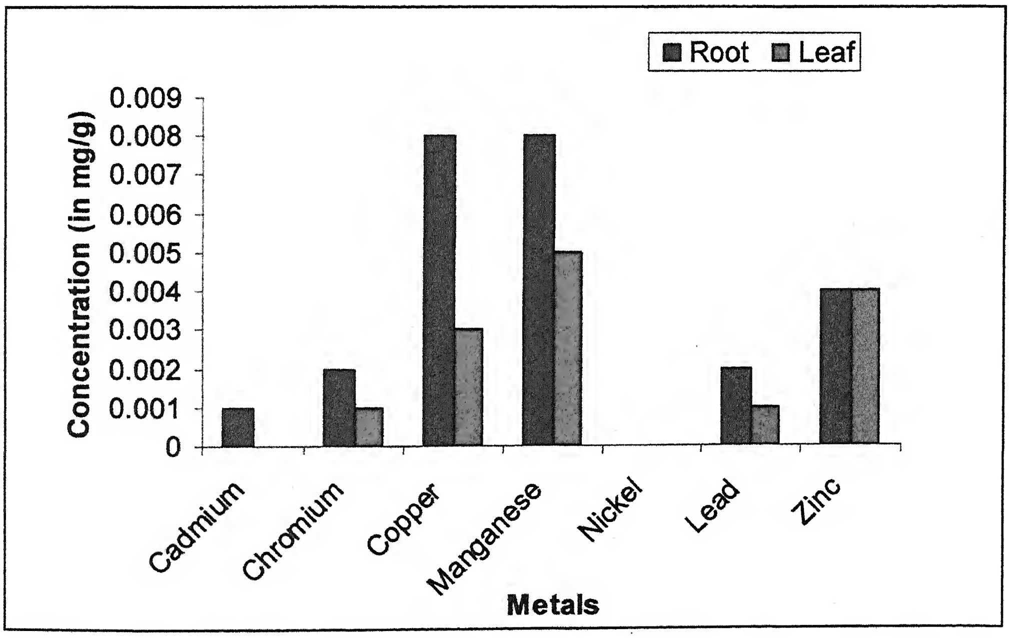



**Figure 5.34. Metal concentration (in mg/g) in roots and leaves of *Eichhornia crassipes* collected from Lakshmital**

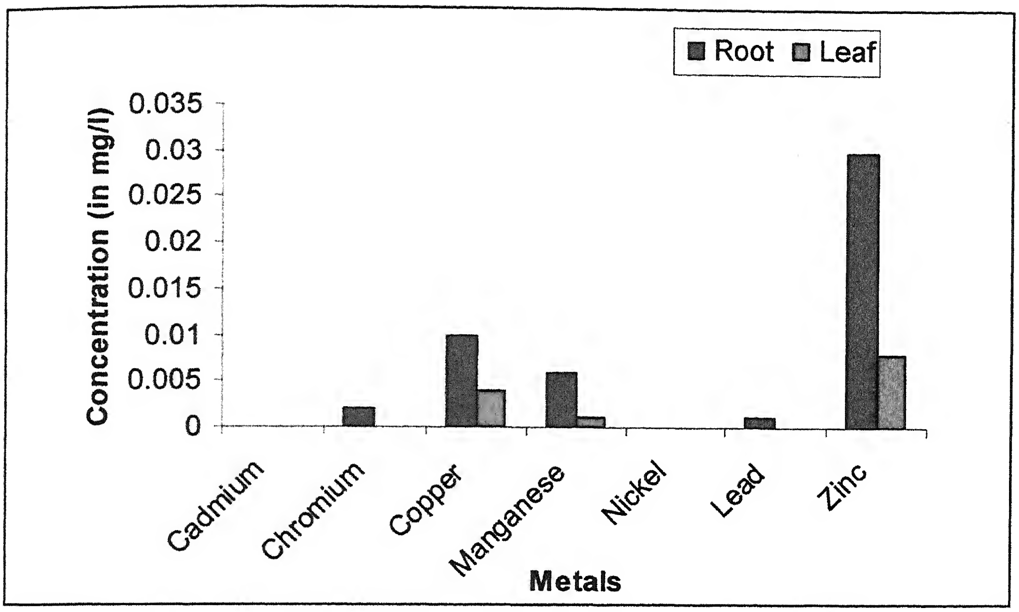



**Figure 5.35. Metal concentration (in mg/g) in roots and leaves of *Potamogeton zosteriformis* collected from Lakshmital**

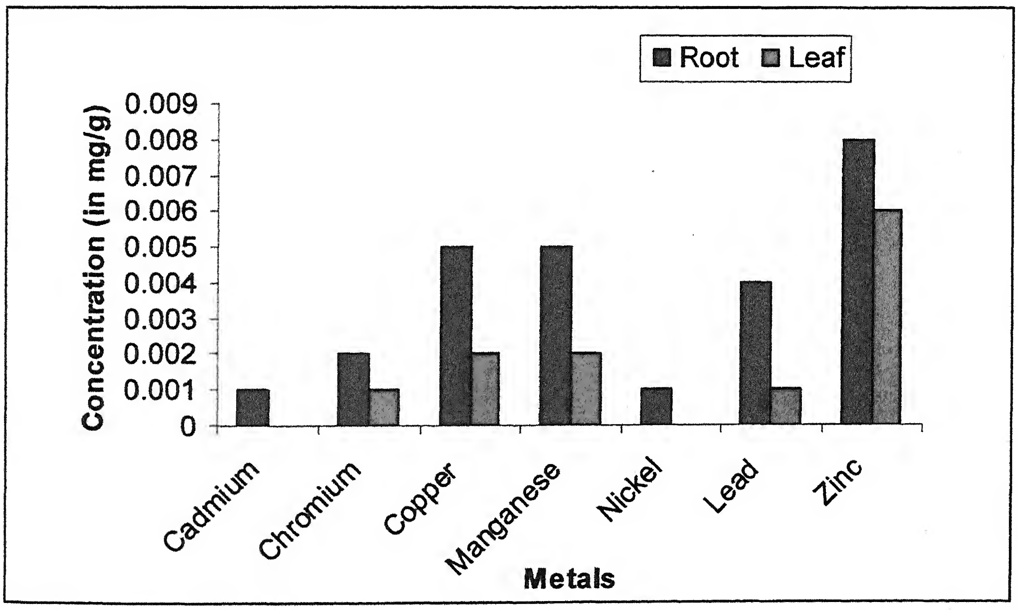



**Figure 5.36. Metal concentration (in mg/g) in roots and leafs of *Elatine triandra* collected from Lakshmital**

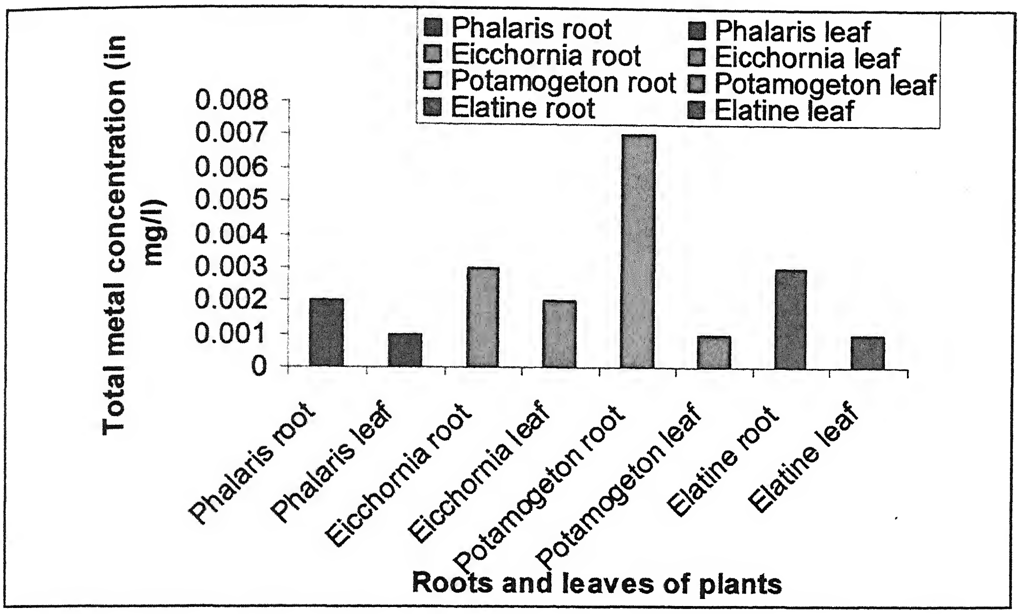



**Figure 5.37. Variation in total metals concentration (in mg/g) in roots and leaves of different plant species collected from Lakshmital**

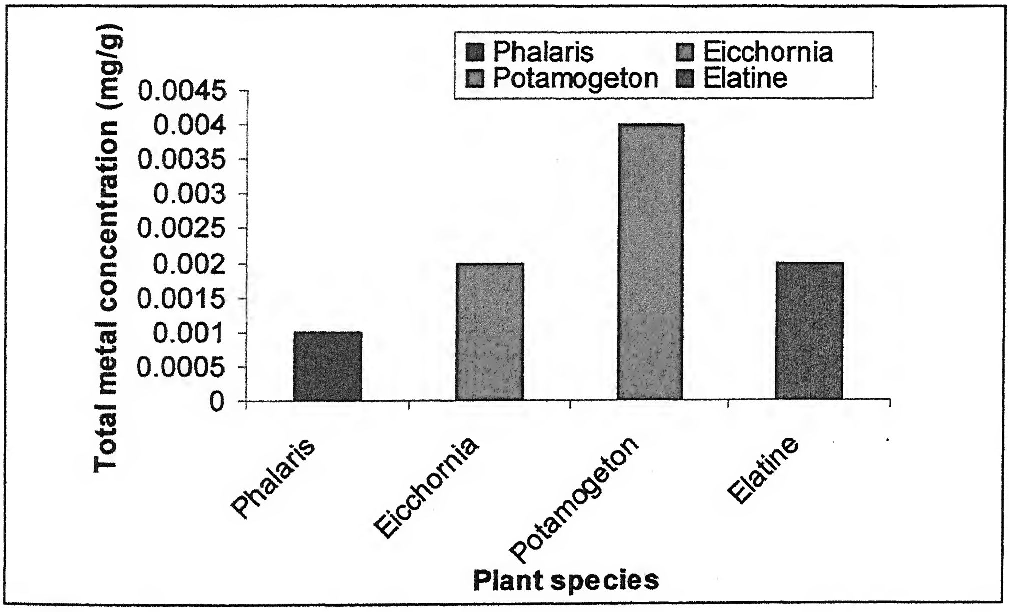



**Figure 5.38. Total metals concentration (in mg/g) in aquatic plant species collected from Lakshmital**

## Correlation coefficient

Correlation coefficients in metals were calculated with the same method, used in physico-chemical parameters. The results obtained are as follows:

### Correlation coefficient between metals

According to **Table 5.12**, mean cadmium showed significant positive correlation (r = 0.348) with nickel. Rest of the metals did not show any significant correlation.

### Correlation coefficient of metals with physico-chemical parameters

Pearson correlation coefficient was calculated to know the interdependence of metals with physico-chemical parameters (pH, phosphate, nitrate and dissolved oxygen) as shown in **Table 5.13**. A significant negative correlation of D O with Cd, Mn, Ni and Pb was observed. Among all the highest correlation coefficient was observed between D O and Pb [r = (-) 908].

**Table 5.12. Correlation coefficients for metals observed in Lakshmital Lake**

| | Cd | Cr | Cu | Mn | Ni | Pb | Zn |
|---|---|---|---|---|---|---|---|
| Cd | 1.000 | | | | | | |
| Cr | .927 | 1.000 | | | | | |
| Cu | .929 | .911 | 1.000 | | | | |
| Mn | .967 | .956 | .966 | 1.000 | | | |
| Ni | .348 | .086 | .436 | .297 | 1.000 | | |
| Pb | .834 | .940 | .739 | .854 | -.183 | 1.000 | |
| Zn | .962 | .949 | .970 | .987 | .319 | .838 | 1.000 |

Correlation is significant at the 0.05 level (2-tailed).

**Table 5.13. Correlation coefficients of metals with annual mean values of four physico-chemical parameters of Lakshmital**

| | pH | $PO_4^{2-}$ | $NO_3^{2-}$ | DO |
|---|---|---|---|---|
| Cd | .142 | .476 | -.089 | -.877 |
| Cr | -.004 | .286 | .219 | -.949 |
| Cu | -.035 | .206 | .266 | -.932 |
| Mn | -.112 | .251 | .139 | -.896 |
| Ni | .188 | .548 | -.153 | -.851 |
| Pb | .096 | .381 | .017 | -.908 |
| Zn | .292 | .802 | -.231 | -.619 |

* Correlation is significant at the 0.05 level (2-tailed).

# Results

## (C) Biological Analysis

In a detailed vegetation survey of Lakshmital, four different aquatic plant species were discovered namely *Phalaris arundinacea, Potamogeton zosteriformis, Eichhornia crassipes, Elatine triandra.* The details of the species are following (**Table 5.14**):

### *Phalaris arundinacea*

*P. arundinacea* belongs to *Poaceae* family and is commonly known as reed canarygrass that is frequent around lowland pools ditches and marshy areas. It is a cool season, perennial weed.

Flowers of canarygrass are hermaphrodite and arranged in dense, branched panicles that can range from 2 to 8 inches in length. Leaf blades are flat, up to 16 inches long, and 1/4 to 3/4 of an inch wide and stems of the plant can reach between 2 and 7 feet in height and are covered with a waxy coating giving the plant a blue-green appearance. Stems are hollow with open sheaths, small clasping auricles, and membranous ligules. Running root system form an impenetrable ground cover.

The leaves of plant are used to weave into hats and mats; and in some areas the grass has been used for erosion control. Reed canarygrass is rated good for streambank stabilization and excellent for rehabilitating waterways and trapping and filtering sediments to prevent erosion. The variegated-leaved variety *picta* L. is sometimes grown as an ornamental under the common name "ribbon

grass" or "gardener's garters". Reproduction in the plant takes place mainly by rhizomes.

### *Potamogeton zosteriformis*

*P. zosteriformis* is commonly known as flatstem pondweed and it comes under *Potamogetonaceae* family. The plant is found nearly worldwide; in ponds, lakes, 1-2.5 m deep.

It is a perennial, submersed aquatic; stems flattened, angled, freely branching plant. Flowers of pondweed are green-brown, small; inflorescence cylindrical spike, spike above the water and fruit is oval shaped, dry seed with a sharp, narrow dorsal ridge. Leaves of the plant are alternate, entire, with prominent midvein; stiff, linear, many fine parallel veins, none floating; firm stipules free in leaf axil. Roots are fibrous and from slender rhizomes. Plant provides wildlife food and habitat and spreads by seeds or by creeping rhizomes.

### *Eichhornia crassipes*

*Eichhornia crassipes* belongs to *Pontederiaceae* family and commonly known as water hyacinth. It is a freshwater aquatic weed worldwide; in lakes, rivers, ponds, ditches of temperate climates. The plant is free-floating and draws all its nutrients directly from water.

Its plant is monocot, perennial, free-floating, except when stranded in the mud; mother plants and daughter plants attached by floating stolons. Flowers of water hyacinth are multiple (8 to 15) flowers in a single very showy, spike (spathe) to 12 in. long; spike at top of erect thick stalk to 20 in. long, rising above the leaves. Each flower is in the flower-spike with six lavender-blue petals

(perianths). Fruit is a capsule, 3-celled, with many seeds. Leaves formed in rosettes rise to three feet above the water; leaves entire, ovate, rounded, circular, or broadly elliptic, to 6 in. wide; thick, glossy, waxy green, waterproof; sides gently incurved and often undulate; leaf base hear-shaped, squared or rounded; veins dense, numerous, fine, longitudinal. Petioles (leaf stems) are floating, creeping; inflated, bulbous, spongy, to 12 in. long. Roots are hanging submersed beneath floating leaves, dark purplish to black with feathery, tips.

The plant of *Eichhornia crassipes* comprises 95% water and 5% dry matter of which 50% is silica, 30% potassium, 15% nitrogen and 5% protein (Makhanu, 1997). It has been known to thrive well in nutrient-enriched fresh waters in tropical climatic zones. For this purpose it has been used in wastewater treatment facilities (Osumo, 2001). The focus on water hyacinth as a key step in wastewater recycling is due to the fact that it forms the central unit of a recycling engine driven by photosynthesis and therefore, the process is sustainable, energy efficient and cost efficient under wide variety of rural and urban conditions (Gijzen, 2000). It is also used as an ornamental in outdoor pools and aquariums and with its bladder like leaf bases, it has been recommended as a source of cellulose for papermaking and other uses.

*E. crassipes* reproduces both vegetatively and sexually, though vegetative reproduction is more important. The plant grows and spreads rapidly under favorable temperature and nutrient conditions. Currents and wind help in its distribution and dispersal.

### *Elatine triandra*

Elatine triandra is commonly known as small waterwort and belongs to *Elatinaceae* family. It is found floating in the shallow waters of lakes and ponds.

Waterwort is a small annual herb small in the form of floating mat on the water. Flowers are small, perfect, sessile, and solitary in the leaf axils, 1.5mm-2 mm across. Fruit is a globose capsule with 1-1.5mm in diameter. Leaves are opposite, sessile, obovate to oblanceolate, mostly truncate or emarginated at the tip, entire. Minute membranous stipules are found in leave axils. Roots are fibrous, unbranched with thread-like structure

Waterwort is usually considered beneficial in stabilizing shorelines. Reproduction takes place by seeds, often distributed by waterfowl.

**Table 5.14. Details of plants habited in Lakshmital Lake**

| Name | *Phalaris arundinacea* L. | *Potamogeton zosteriformis* Fernald | *Eichhornia crassipes* | *Elatine triandra* |
|---|---|---|---|---|
| **Common name** | **Canary grass** | **Pondweed** | **Water hyacinth** | **Small waterwort** |
| **Taxonomy** | | | | |
| **Kingdom** | *Plantae* – Plants | *Plantae* – Plants | *Plantae* – Plants | *Plantae* – Plants |
| **Subkingdom** | *Tracheobionta* – Vascular plants | *Tracheobionta* – Vascular plants | *Tracheobionta* – Vascular plants | *Tracheobionta* – Vascularplants |
| **Superdivision** | *Spermatophyta* – Seed plants | *Spermatophyta* – Seed plants | *Spermatophyta* – Seed plants | *Spermatophyta* – Seed plants |
| **Division** | *Magnoliophyta* – Flowering plants | *Magnoliophyta* – Flowering plants | *Magnoliophyta* – Flowering plants | *Magnoliophyta* – Flowering plants |
| **Class** | *Liliopsida* – Monocotyledons | *Liliopsida* – Monocotyledons | *Liliopsida* – Monocotyledons | *Magnoliopsida* – Dicotyledons |
| **Subclass** | *Commelinidae* | *Alismatidae* | *Liliidae* | *Dilleniidae* |
| **Order** | *Cyperales* | *Najadales* | *Liliales* | *Theales* |
| **Family** | *Poaceae* – Grass family | *Potamogetonaceae* – Pondweed family | *Pontederiaceae* – Water-Hyacinth family | *Elatinaceae* – Waterwort family |
| **Genus** | *Phalaris* L. – canarygrass | *Potamogeton* L. – pondweed | *Eichhornia* Kunth – water hyacinth | *Elatine* L. – waterwort |
| **Species** | *Phalaris arundinacea* L. – reed canarygrass | *Potamogeton zosteriformis* Fernald – flatstem pondweed | *Eichhornia crassipes* (Mart.) Solms – common water hyacinth | *Elatine triandra* Schkuhr – threestamen waterwort |
| **Habitat** | Frequent around lowland pools ditches and marshy areas | Nearly worldwide; in ponds, lakes, 1-2.5 m deep | An aquatic weed worldwide; in lakes, rivers, ponds, ditches of temperate climates | Mud flats or floating in the shallow waters of lakes and ponds |
| **Description** | *Plant:* cool season and perennial.<br><br>*Flowers:* are hermaphrodite and arranged in dense, branched panicles that can range from 2 to | *Plant:* perennial, submersed aquatic; stems flattened, angled, freely branching; slight rhizomes<br><br>*Flower:* green-brown, small; inflorescence cylindrical spike, | *Plant:* monocot, perennial, free-floating, except when stranded in the mud; mother plants and daughter plants attached by | *Plant:* A small, matted, annual herb<br><br>*Flower:* small, perfect, sessile, and solitary in the leaf axils, 1.5mm-2 mm across. |

| | | | | |
|---|---|---|---|---|
| | 8 inches in length.<br><br>*Leaf:* blades are flat, up to 16 inches long, and 1/4 to 3/4 of an inch wide.<br><br>*Stems:* of the plant can reach between 2 and 7 feet in height and are covered with a waxy coating giving the plant a blue-green appearance. Stems are hollow with open sheaths, small clasping auricles, and membranous ligules.<br><br>*Root:* running root system and form an impenetrable ground cover. | spike above the water<br><br>*Fruit:* oval, dry seed with a sharp, narrow dorsal ridge<br><br>*Leaf:* alternate, entire, with prominent midvein; stiff, linear, many fine parallel veins, none floating; firm stipules free in leaf axil<br><br>*Root:* Fibrous, from slender rhizomes | floating stolons<br><br>*Flower:* multiple (8 to 15) flowers in a single very showy, spike (spathe) to 12 in. long; spike at top of erect thick stalk to 20 in. long, rising above the leaves; each flower in the flower-spike with six lavender-blue petals (perianths).<br><br>*Fruit:* a capsule, 3-celled, with many seeds<br><br>*Leaf:* leaves formed in rosettes rise to three feet above the water; leaves entire, ovate, rounded, circular, or broadly elliptic, to 6 in. wide; thick, glossy, waxy green, waterproof; sides gently incurved and often undulate; leaf base hearshaped, squared or rounded; veins dense, numerous, fine, longitudinal<br><br>*Petioles (leaf stems):* floating, creeping; inflated, bulbous, spongy, to 12 in. long<br><br>*Roots:* hanging submersed beneath floating leaves, dark purplish to black, feathery, tips with long root caps | *Fruit:* a globose capsule , 1-1.5mm in diameter, membranous<br><br>*Leaf:* opposite, sessile, obovate to oblanceolate, mostly truncate or emarginated at the tip, entire. Minute membranous stipules in leave axils<br><br>*Roots:* fibrous, unbranched, thread-like |
| **Importance of plant** | The leaves of plant are used to wove into hats and mats; | Plant provides wildlife food and habitat. | It is used as an ornamental in outdoor pools and aquariums; | Usually considered beneficial in stabilizing shorelines. |

| | | | | |
|---|---|---|---|---|
| | In some areas, the grass has been used for erosion control;<br><br>Reed canarygrass is rated good for streambank stabilization and excellent for rehabilitating waterways and trapping and filtering sediments to prevent erosion<br><br>The variegated-leaved variety *picta* L. is sometimes grown as an ornamental under the common name "ribbon grass" or "gardener's garters". | | Water hyacinth, with its bladder like leaf bases, has been recommended as a source of cellulose for papermaking and other uses;<br><br>There has been some use of *E. crassipes* for removal of nutrients and heavy metals from sewage and sludge ponds. | |
| **Reproduction** | Reed canarygrass reproduces mainly by rhizomes. | It spreads by seeds or by creeping rhizomes. | *E. crassipes* reproduces both vegetatively and sexually, though vegetative reproduction is more important. *E. crassipes* grows and spreads rapidly under favorable temperature and nutrient conditions. | By seeds, often distributed by waterfowl. |


Plate 5.1. Growth of *Phalaris arundinacea* in Lakshmital Lake

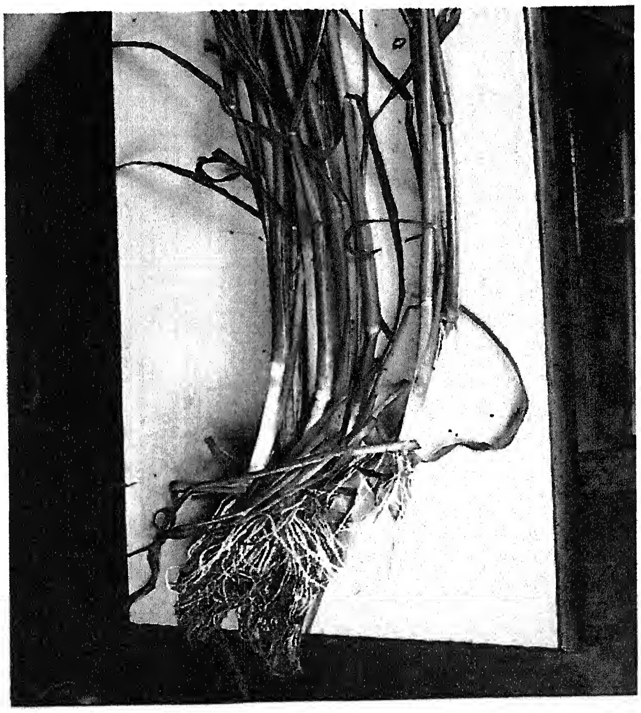


Plate 5.2. Individual species of *Phalaris arundinacea*

**Plate 5.3. Growth of *Potamogeton zosteriformis* in Lakshmital Lake**

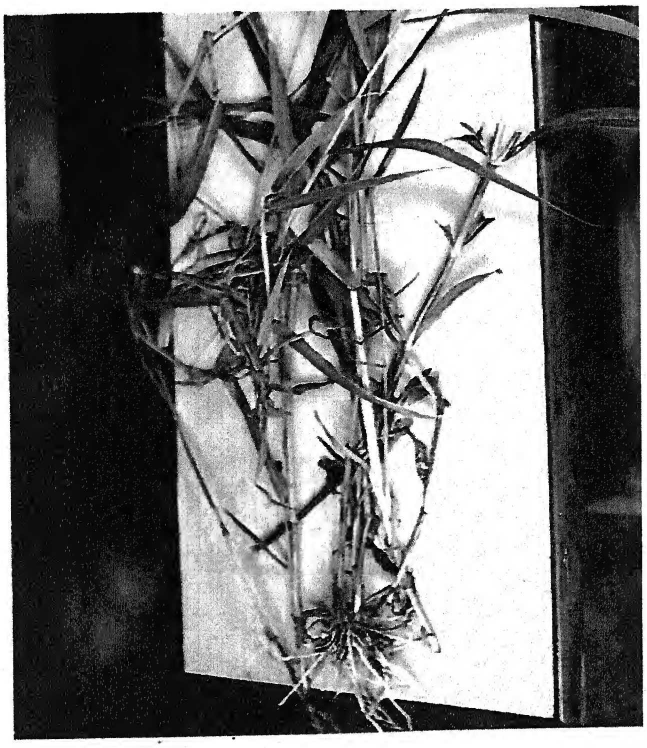


**Plate 5.4. Individual species of *Potamogeton zosteriformis***

**Plate 5.5. Growth of *Eichhornia crassipes* in Lakshmital Lake**

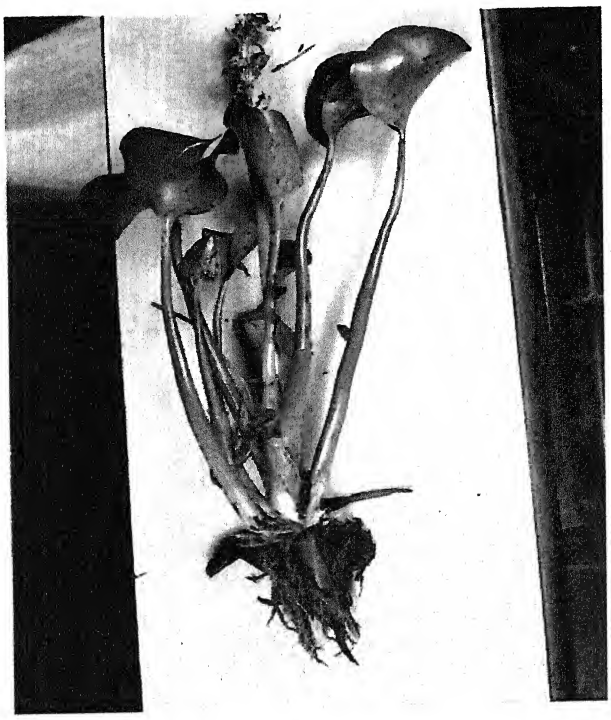


**Plate 5.6. Individual species of *Eichhornia crassipes***

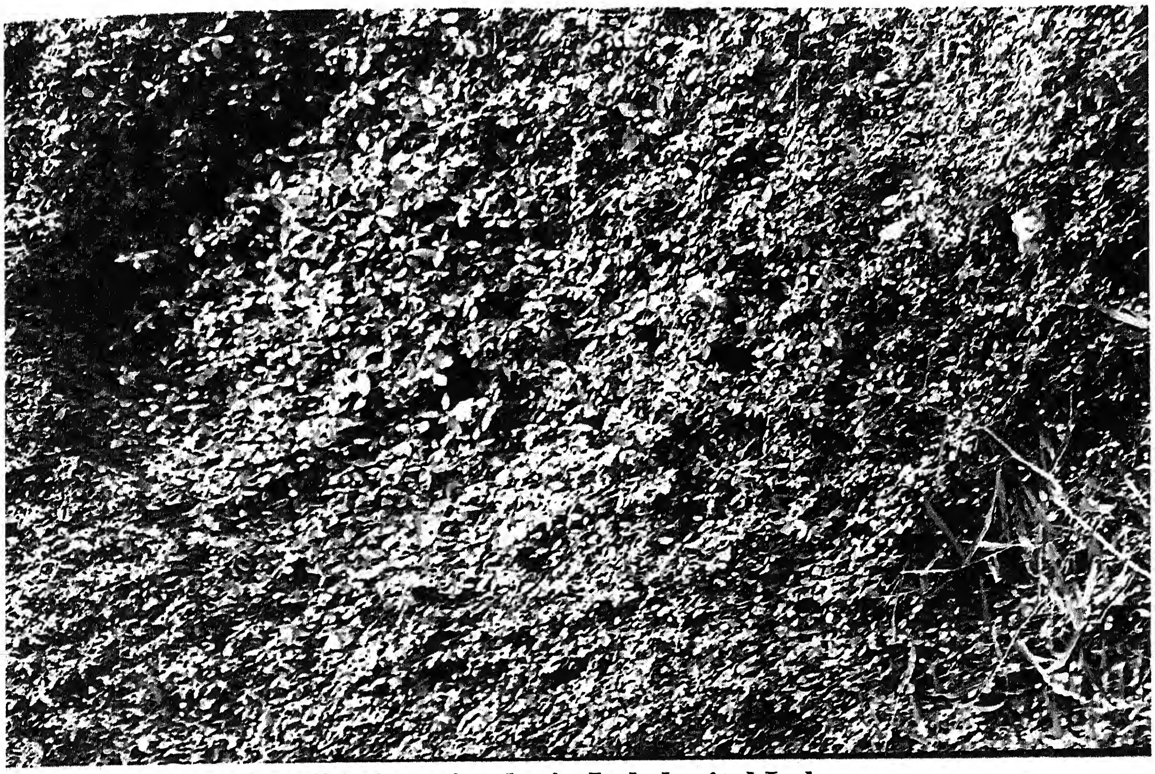


**Plate 5.7. Growth of *Elatine triandra* in Lakshmital Lake**

**Plate 5.8. Individual species of *Elatine triandra***

## Results

## (D) Socio-economic Analysis

Socio-economic conditions in the surroundings of any aquatic body is an important component in the assessment of ecosystem health of that water body because it determines the economic dependency of the people living in the fringes of these lakes as well as impact of people's activities on the lake quality. In Lakshmital a total of 200 households surveyed in the catchment area, based on a questionnaire, containing demographic information, economic status, water usage pattern, waste management and sanitation conditions availability. Questions were presented to the individuals orally and information gathered was recorded onto a survey form. The results obtained through survey area as follows:

Regarding *family size* of the population residing in the localities near Lakshmital, a maximum (55%) population had small families with 1-5 individuals. 31% families had 6-10 persons and 14% large families were found with 11-15 members (**Figure 5.39**).

200 of the houses, 34% of the population was under middle *age group* (i.e. 26-50 years), 58% people belonged to two age groups (1-15 years and 16-25 years) while, a very low percentage (8%) was above 50 years as shown in
**Figure 5.40**.

Out of the 200 households surveyed maximum population (24%) was in government *services* at different levels from peon to officer ranks, 28% were shopkeepers; most of the shops are of general stores or vegetable shops. A good

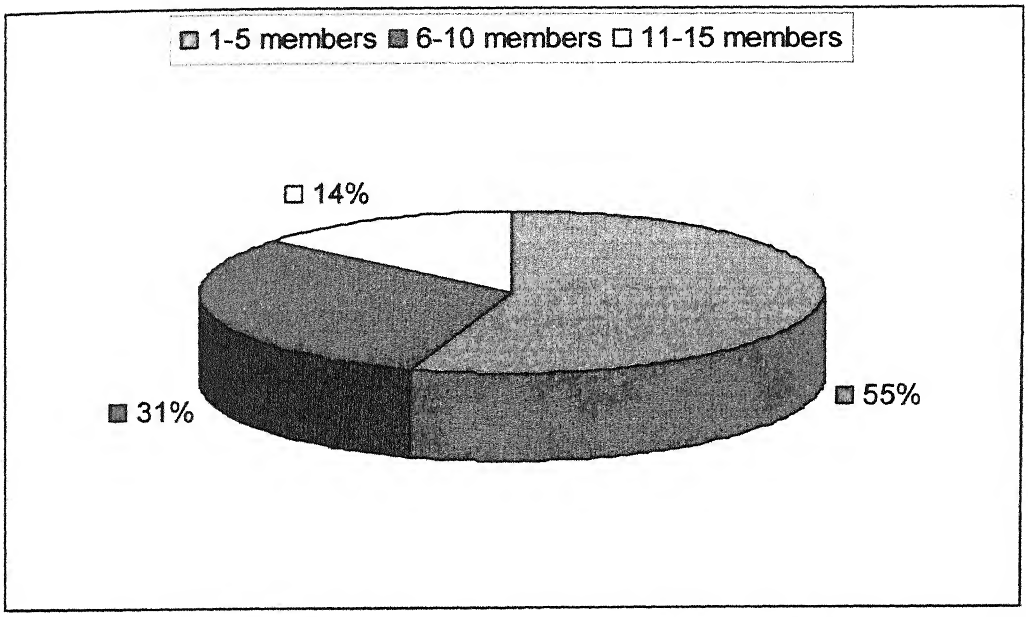



**Figure 5.39. Average family size in the localities near Lakshmital**

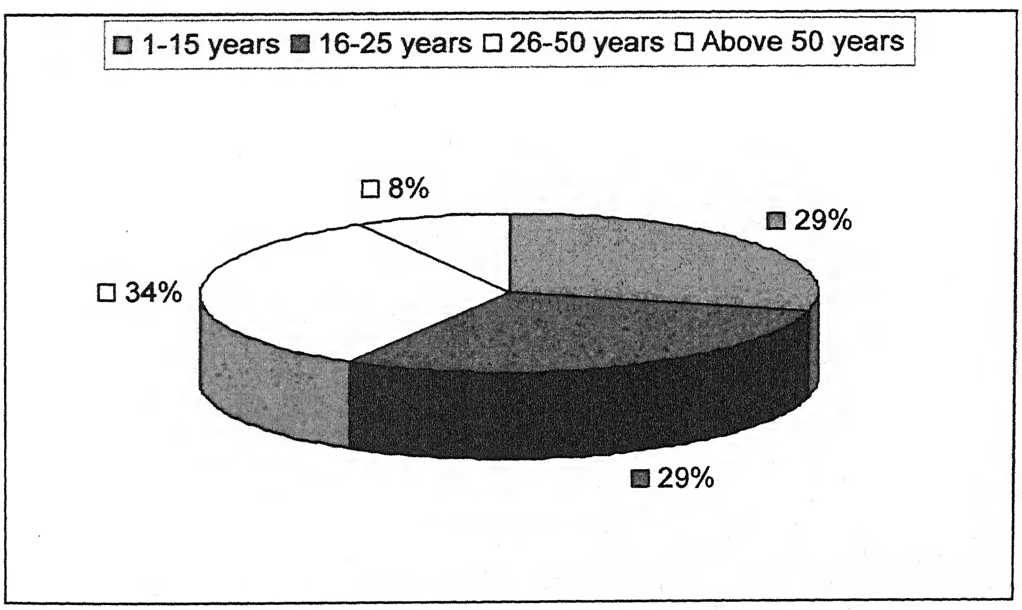



**Figure 5.40. Age groups in the population of localities near Lakshmital**

percentage (17%) of sweepers also lived in the catchment of Lakshmital. Only 7% of the residing population had their own business (**Figure 5.41**).

*Income level* of any population depends on the type of occupation. The people residing in the catchment area of Lakshmital were scattered under different income groups (**Figure 5.42**). 49% of the respondents had annual income between 10,000 to 50,000 Rs.. 24% of the households had their annual earning between 51,000 to 1,10,000 Rs. While, only 18% people belonged to annual income group of 1,10,000 – 2,50,000 Rs. and 9% had income above 2,60,000 Rs. in the houses surveyed in the fringes of Lakshmital.

All respondents used municipal *water supply* to meet their domestic water needs, with alternatives of hand pumps and wells for emergency period. 13% of population used only 100-300 l/d water. 37% of the peoples consumed 210-300 l/d water. 20% population had 310-400 l/d water demand and 27% households utilized 410-500 l/d water while, only a small percentage of peoples utilized water above 500 l/d as shown in **Figure 5.43**.

According to **Figure 5.44**, *duration of residency* ranged from 10 to above 50 years and 7% of the families had lived in the area above 50 years. 56% of the residents were living for last 10-20 years while 23% of the households are 31-40 years old. 7% of the surveyed people were residing in the area for last 21-30 years and 7% houses were 41-50 years old.

*Estimation of the deterioration in the quality of lake* varied from 1 to 12 years, over half of the estimates ranged form 10-12 years. 37% of respondents noticed lake degradation for last 7-9 years while only 10% population estimated it for last 1 to 6 years (**Figure 5.45**).

A household discharged around 216.24 litres of *waste water* per day in the Lakshmital while *solid waste* generated and disposed either in the drains or directly to the lake amounted to about 1.18 kg/day per household for the catchment residents in the Lakshmital. 60% of the total waste generated in households are biodegradable waste while, 40% of the waste comprised of non-biodegradable waste (**Figure 5.46**). Despite the location of the lake in the urbanized area, it was noticed that 10% of the houses surveyed were not accessed to modern toilet facilities or without a proper toilet.

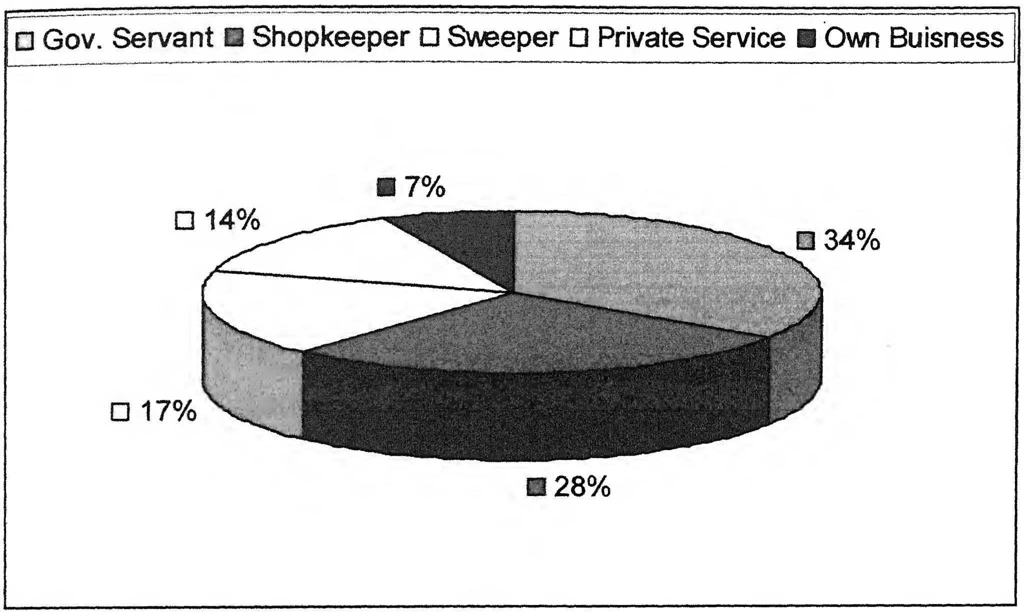



**Figure 5.41. Occupations types in the population of localities near Lakshmital**

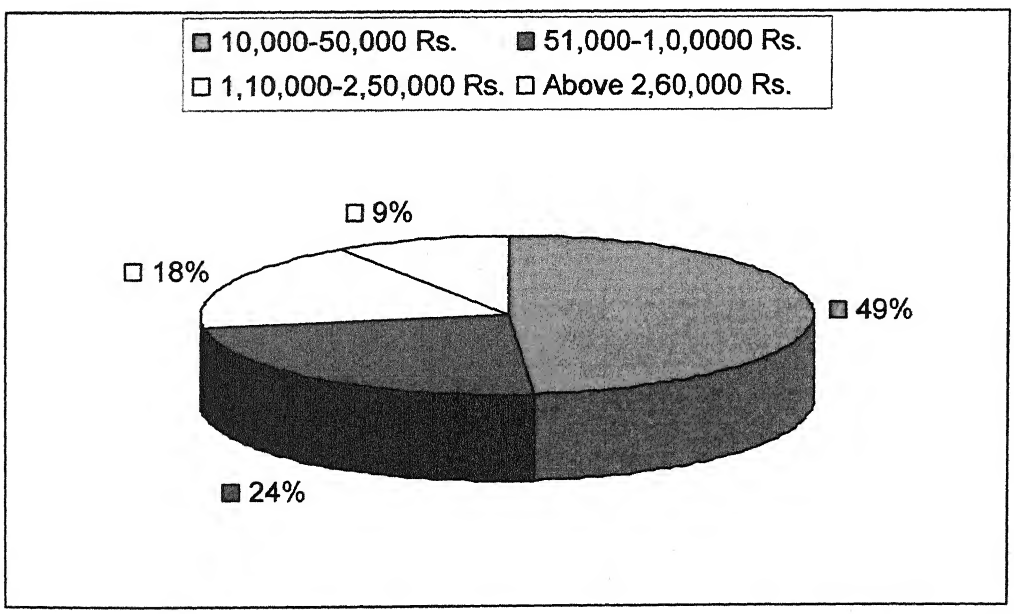



**Figure 5.42. Annual Income distribution (in Rupees) in the population of localities near Lakshmital**

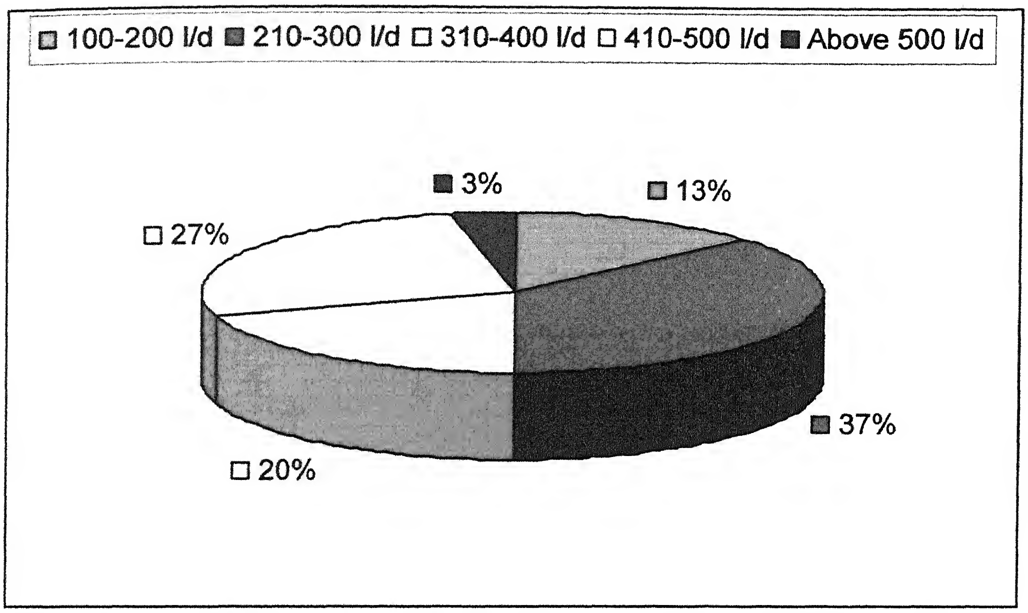



**Figure 5.43. Water consumption pattern (in litres/day) in the population of localities near Lakshmital**

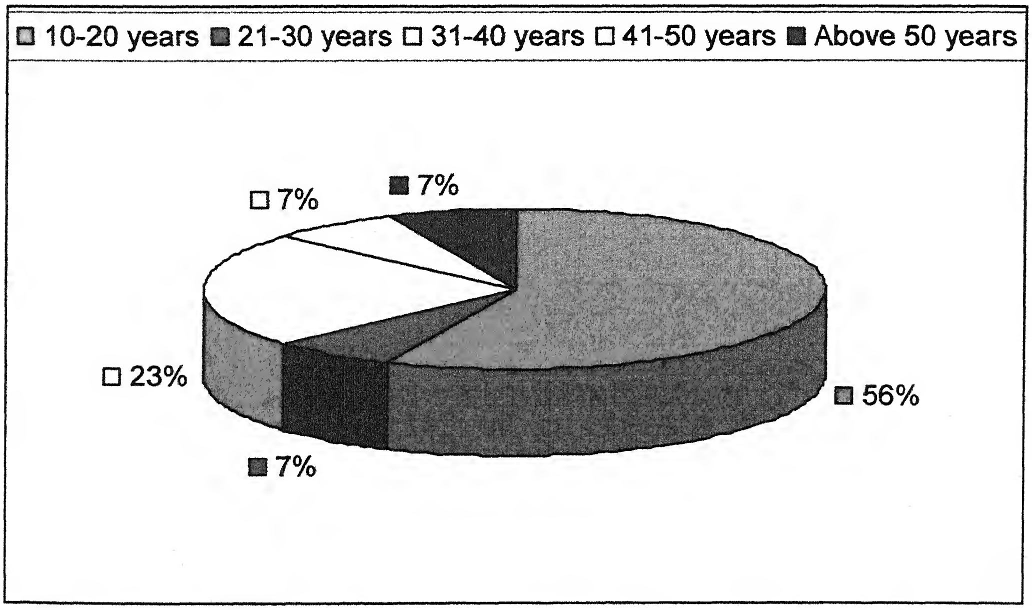



**Figure 5.44. Time of residence (in years) of the population in localities near Lakshmital**

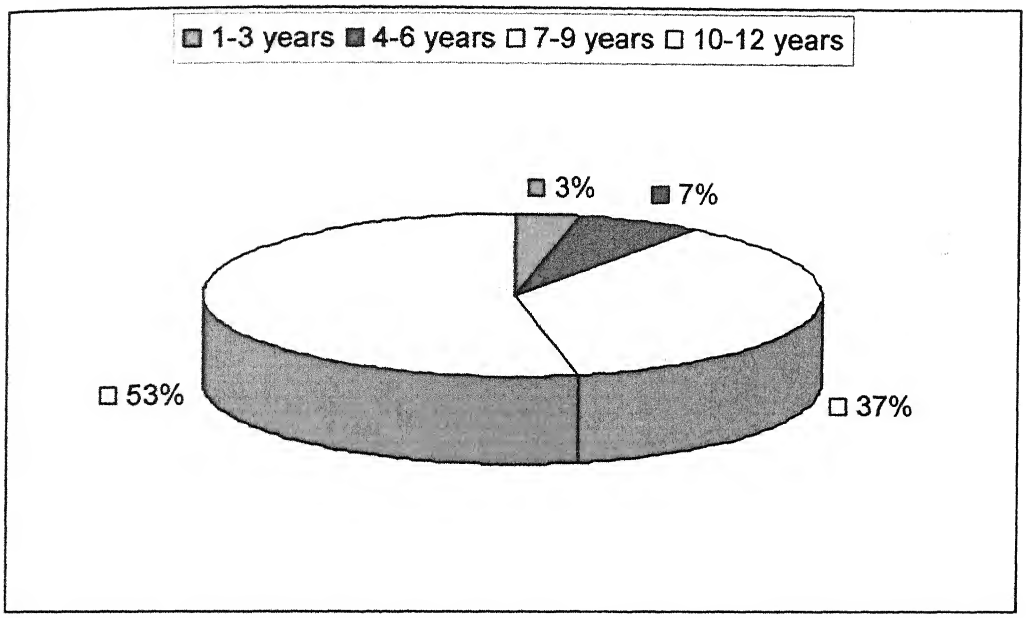



**Figure 5.45. Deterioration in water quality of lake in past years as per opinion of nearby residents**

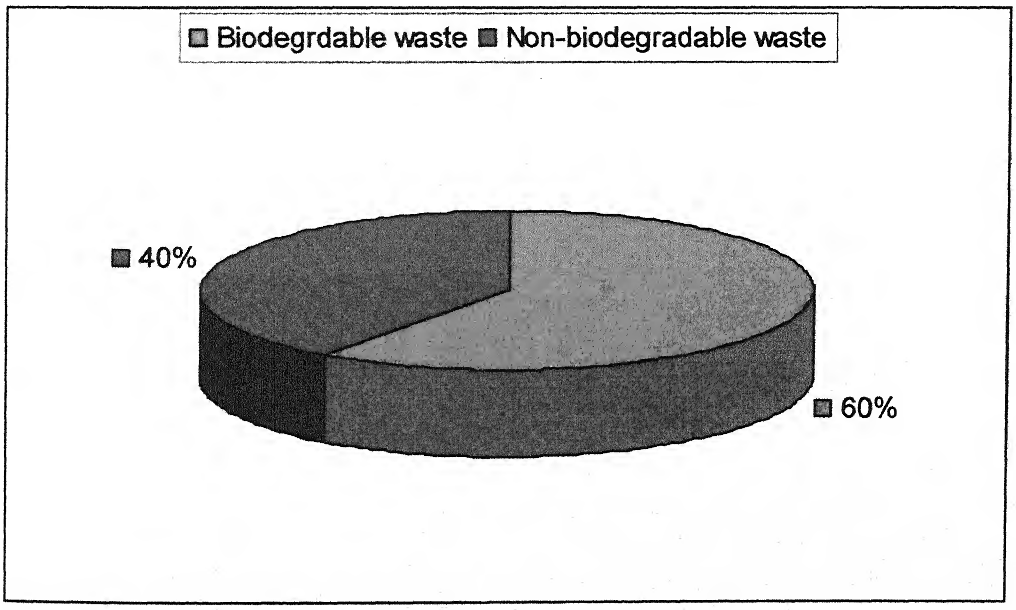



**Figure 5.46. Type of waste generated by the population of localities near Lakshmital**

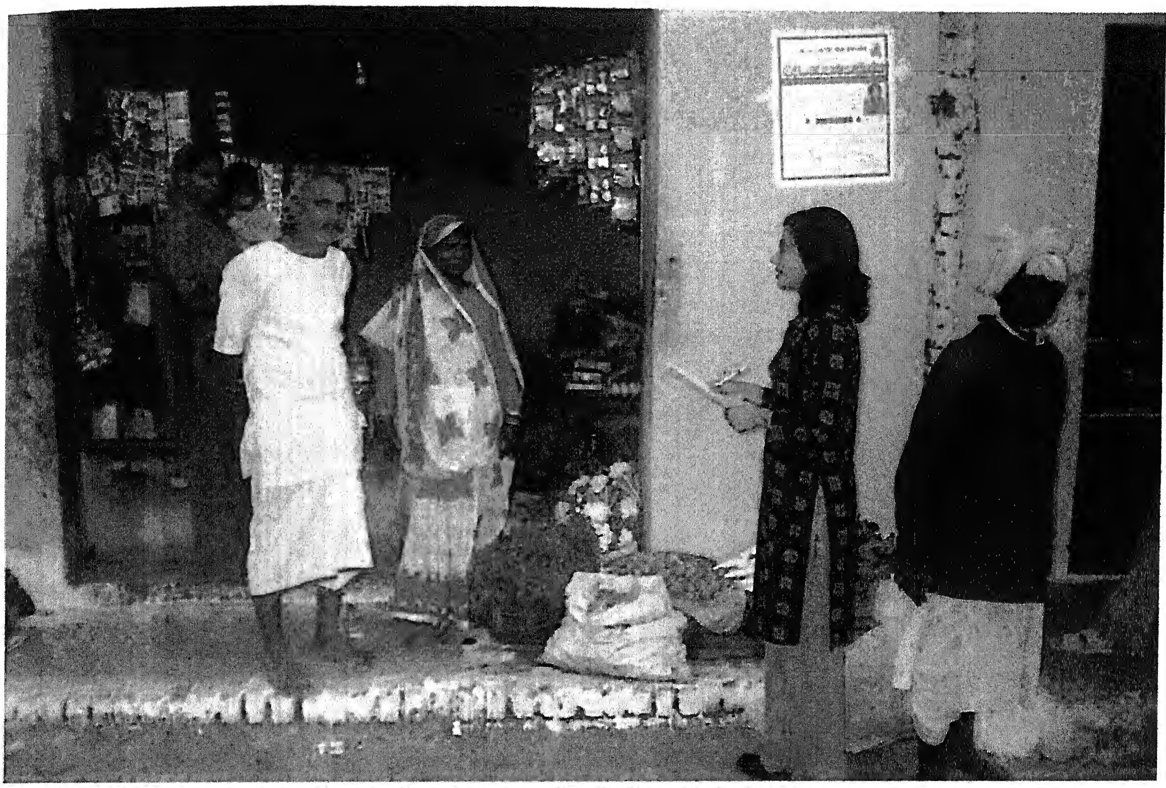


**Plate 5.9. Interview of residents near Lakshmital during socio-economic survey**

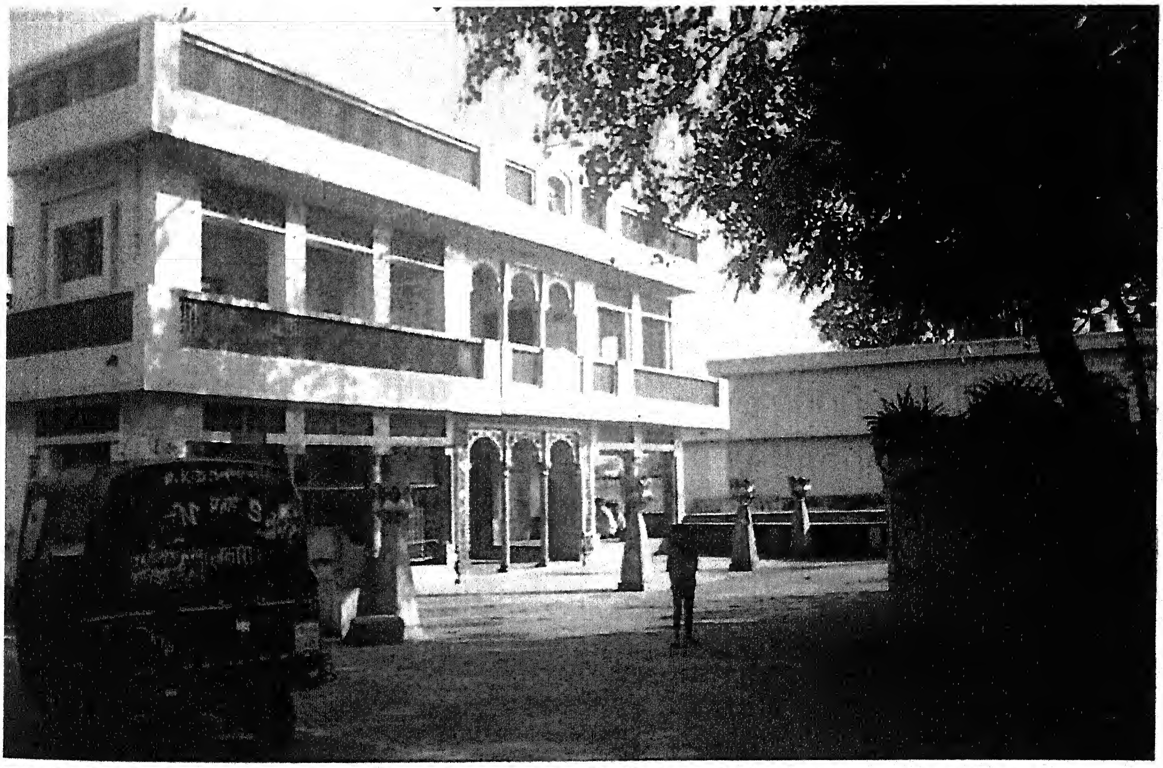


**Plate 5.10. Lakshmi temple adjacent to Lakshmital, showing its religious and historical value**

# Discussion

The results obtained in the present study for Lakshmital have been discussed under four sections which are as follows:

(A) Physico-chemical characteristics; (B) Metals concentration; (C) Biological characteristics, and Socio-economic conditions

## (A) Physico-Chemical Characteristics

Water is not only precious resource but is also indispensable. Indeed, the economics of all life processes and living communities are hinged on this most vital and major abiotic component (Tonapi, 1980). Only about 0.1% water is available as fresh water in rivers, lakes, ponds and streams, which is suitable for human consumption. Keeping all these factors in mind, the studies on tropical limnology have accumulated many significant findings since the exploratory ventures of Juday (1915) and Rutner (1931). But there are still lots to achieve in present development scenario in particular with lentic habitat in general.

The present investigation was undertaken to collect the relevant hydro-biological and socio-economic data of fresh water lake 'Lakshmital' at Jhansi in Uttar Pradesh. Observations on physico-chemical characteristics of Lakshmital suggest that the various physical and chemical characteristics are related to their seasonal and spatial changes and in most instances are interdependent. Distinct seasonal variations are exhibited by most of the parameters. Detail description of physico-chemical characteristics of Lakshmital is as follows:

*Temperature* is basically an important factor for its effects on chemical and biological reactions in water. It regulates physico-chemical processes of the

entire ecosystem. The sediments heat budget and thermal stratification contribute significantly in controlling the metabolic characteristics of the ponds and lakes in both temperate and tropical regions (Welch, 1935; Hutchinson, 1957; Ganpati, 1957 and 1960; Sreenivasan, 1964). In contrast to temperate lakes and ponds, relatively small annual income and loss of heat have been noticed in tropical lakes (Lewis 1973; Wetzel, 1975). The temperature of natural inland waters in tropics generally varies between 25-35$^0$C (Alabaster *et al.*, 1980). In the present study, the temperature varied from 26.53$^0$C to 28.06$^0$C, irrespective of all sites and seasons i.e. within the permissible limits (>50$^0$C) of EPA standards. The maximum temperature was recorded on sewage inflow site that was due to constant input of sewage, caused higher pollution levels and increased microbial activities. The homothermal condition was found during the study, and there was no permanent thermocline and fluctuation in temperature lasted for a short duration. Similar temperatures were exhibited by Tripathi *et al.* (1999) in Gavinath pond (24.20 to 30.20$^0$C), Ramalingam (2004) in Velachery Lake (25-32$^0$C) and Das *et al.* (2007) in three tropical water reservoirs in Eastern India. Maximum temperature was reported in summer season followed by rainy and winter seasons. Temperature depends strongly on weather conditions; therefore, maximum temperature in summer may be attributed to clear atmosphere and greater isolation from the sun and low water level. Low temperature in rainy and winter were due to high water levels, higher percentage of humidity due to low evapo-transpiration rate and increased soil moisture contents. Similar seasonal fluctuations in temperature were reported by Jain *et al.* (1999), Jha *et al.* (2003), Rudezyk *et al.* (2002), Gengerke *et al.* (1972) and Chaudhari *et al.* in 2001. According to Alabaster *et al.*, (1980) aquatic organisms have adaptability to withstand with such seasonal changes including variation outside this range.

In *well waters*; minimum temperature was obtained in well water near Kali temple because the well was shaded that prevent it from direct sun heating.

Temperature showed significant positive correlation with iron in all the seasons but had a significant negative correlation with total hardness, calcium and magnesium during winter and pre-monsoon seasons. In post-monsoon season, a significant negative correlation of temperature was obtained with turbidity, total suspended solids, total dissolved solids and total solids that were due to low temperature during the season that leaded deposition of total suspended solids, total dissolved solids and total solids coming with the surface run-off and caused indirect increase in turbidity. In mean annual correlation temperature possessed significant positive correlation with total alkalinity that was due to increase amount of the inorganic carbon in the system by increased photosynthesis and respiration activities at elevated temperature levels. Rudezyk *et al.* (2002) obtained a significant negative correlation temperature with total dissolved solids and ammonia that confirms the findings of present study. In a study by Jha *et al.* (2003) on Lake Mirik, a positive correlation was observed between temperature and dissolved oxygen. On contrary, a significant negative correlation (r = -0.858) was found between dissolved oxygen and temperature by Kumari *et al.* (2007) in two Tropical Model Ponds in India. It was justified that by increasing temperature, the diffusion rates of solutes also increased that reduced the solubility of oxygen.

*pH* is a scale of intensity of acidity or alkalinity and measures the concentrations of $H^+$ ions (arising from the dissociation of $H_2CO_3$) and from $OH^-$ ions (resulting from the hydrolysis of bicarbonates). In a water body pH controls the chemical state of many nutrients including dissolved oxygen, phosphate, nitrate etc. (Goldman and Horne, 1983). At a given temperature pH is controlled by the dissolved chemical compounds and the biological processes

in the solution (Chapman, 1996). In Lakshmital pH was recorded alkaline in nature but within the permissible limits for inland surface waters (5.5 to 9.0) as guided by EPA standards. Sewage inflow site and region adjacent to boundary wall exhibited the maximum pH due to constant input of sewage and low water level. Ramalingam (2004) also observed alkaline pH conditions (7.2 to 8.2) in Valchery lake, Chaudhari *et al.* (2001) recorded a very high pH range (7.68 to 9.85) in Chatri lake. Similar results were showed by Dixit *et al.* (2005) in upper lake of Bhopal. In contrary, Jha *et al.* (2003) and Zutshi *et al.* (1972) and Rawat *et al.* (1993) reported the acidic nature of Himalyan lakes. Maximum pH was reported during pre-monsoon season followed by post-monsoon and winter seasons. The higher value of pH in pre-monsoon season might be due to the increased primary production in aquatic ecosystems (Zafar 1996 and Mussadiq *et al.*, 2001) and also the high rate of photosynthetic activity will raise the pH (Parkins, 1976). The algae in water utilize $CO^2$, which creates more basic conditions. In other seasons dilution of water got pH decreased. Present study has been supported by findings of Ramalingam (2004), Chaudhari *et al.* (2001), Theriot *et al.* (1997) and Kaverina *et al.* (2005).

During winter season pH exhibited significant negative correlation with calcium and total alkalinity and in pre-monsoon season, it showed significant negative correlation with sulphate because at a given temperature pH was controlled by the dissolved chemical compounds (Chapman, 1996). However, in pre-monsoon season pH possessed significant positive correlation with turbidity and in mean annual, it had significant positive correlation with ammonia that was due to contribution to turbidity by top soils, rocks and minerals which caused an increase in pH by creating more basic conditions while ammonia was a major end product of bacterial decomposition of organic matter (Wetzel, 1983) that was directly related to high level of turbidity. A study conducted by Muri in 2004, on 14 Slovenian Mountain Lakes supports

the present findings by observing significant negative correlation of pH with alkalinity and calcium.

*Turbidity* in natural water is caused by suspended matter like clay, silt, organic matter, phytoplankton and other microscopic organisms. Turbidity may be caused by a wide variety of suspended solids and organic colloidal compounds to coarse dispersion (Iqbal *et al.*, 1995) Dissolution of top soils, rocks, minerals and street washings contribute much inorganic and some organic turbidity. Organic materials serve as food for bacteria and resulting bacterial growth and other micro-organisms that feed upon bacteria to produce additional turbidity. It is actually the expression of optical property (Tyndall Effect) in which the light is scattered by the suspended particles present in water (Saxena, 1989). In Lakshmital sewage inflow region depicted the highest turbid water that could be attributed to continuous sewage pollution from point source and presence of low water level. In the present study, turbidity values exceeded the permissible limits (25 mg/l) as suggested by WHO (1971). Similar investigations were also made by Iqbal *et al.* (1995). They reported turbidity ranged from 7 NTU to 92 NTU in upper lake of Bhopal. On contrary, Deswal *et al.* (2006) in Brahm Sarovar (2.9 to 5.2 NTU) and Ramalingam (2004) in Velachery lake (3.02 to 22.5 NTU) observed low range of turbidity that indicated the low amount of particulate matter present in the water. Seasonal observations revealed maximum turbidity during post-monsoon season (86.00 NTU) followed by pre-monsoon and winter seasons. This might be due to increase in sedimentation with influx of monsoon runoff which alternately affect the depth and productivity. Naik *et al.* (1996) also observed the maximum turbidity during the post-monsoon season in Tilaknagar pond of Rourkela, the findings support the present study.

Well waters exhibited the minimum turbidity among all sites. In well water adjacent to Bhutnath temple, turbidity was reported slight above the permissible limits for drinking water because this well was open that leaded to direct intake of air and water pollution. Well water near Kali temple depicted turbidity within permissible limits because this well was covered that prevented direct input of pollutants.

In all seasons turbidity exhibited significant negative correlation with calcium and magnesium in pre-monsoon season while in annual mean, it had significant negative correlation with sulphate because turbidity in the lake was caused by a wide variety of suspended solids and organic colloidal compounds to coarse dispersion (Iqbal *et al.*, 1995) whereas calcium, magnesium and sulphates were found in dissolved form in aquatic bodies and caused hardness. A significant positive correlation of turbidity with fluoride was obtained in post-monsoon season.

The *electrical conductivity* in water is due to ionization of dissolved inorganic solids. It is related to total dissolved solids and is reciprocal of electrical resistance. Conductivity of water samples gives ideas about the physiological effects of ions on plants or chemicals and corrosion rates and also to evaluate variations in dissolved mineral concentration of water sample (APHA, 1989; Alhajjar *et al.*, 1990). The conductivity also reflects the level of water salinity (Moiseenko *et al.*, 1996). In present study conductivity varied spatially and temporally, that exceeded the permissible limits (300 μmhos/cm) as prescribed by the ICMR. Region adjacent to boundary wall exhibited the maximum conductivity value as the site was shallow and had low mixing of water as compared to other sites that caused accumulation of ions, dissolved solids and nutrients at high rate. Ramalingam (2004) in Velachery lake (1510 to 2325 μmhos/cm), Tripathi *et al.* (1999) in Gavinath pond (1011 to 1310 μmhos/cm),

Sublette *et al.* (1967) in Playa lakes (80 to 1250 μmhos/cm) and Chadrashekar *et al.* (2003) in Bellandur lake (2120 to 2750 μmhos/cm) also reported high ranges of conductivity. On the other side, Chattopadhyay *et al.* (2002) observed low range of conductivity in East Calcutta wetland ecosystem.

The higher values of conductivity during pre-monsoon season as compared to winter and post-monsoon season might be due to high temperature gradient that increased the evapo-transipiration rate of the lake leading to low water level and constant inflow of sewage and waste. The work carried out by Kaverina *et al.* (2005) in lake Imandra and Naik *et al.* (1996) in two community ponds of Rourkela recorded same seasonal pattern in conductivity. Rawson (1960) has used the conductivity as an indicator of the trophic status of water bodies. According to him the conductivity values between 126 and 200 μmhos/cm are indicative of eutrophication. Conductivity values in the present study are much higher than the above range, so it indicates eutrophic condition of Lakshmital.

Conductivity during winter season showed significant positive correlation with fluoride, phosphate, potassium and chemical oxygen demand because in winter season, water level of the lake was low that caused accumulation of dissolved solids and nutrients at high rate and conductivity in water expressed the ionization of dissolved inorganic solids. In pre-monsoon season conductivity exhibited significant positive correlation with iron that can be attributed to the highest concentration of iron in the lake during pre-monsoon season. During post-monsoon season conductivity had significant positive correlation with phosphate that elevated the conductivity with its high concentration in the season. Significant negative correlation of conductivity was observed with magnesium, total alkalinity, sulphate and calcium because conductivity reflects the level of water salinity (Maoiseenko *et al.*, 1996) while, alkalinity neutralize strong acids and bases like carbonates and bicarbonates that contribute to

alkalinity. Muri (2004) obtained significant positive correlation of conductivity with sodium, potassium and calcium; in case of potassium it supports the results of present study.

*Total solids* are the measure of the amount of all kinds of solids in water. They do not include any gas and colloids (Trivedi *et al.*, 1987) Saxena (1998), explained that the disposal of both suspended and dissolved solids leads to sedimentation. Alabaster *et al.* (1980) reported that excessive concentrations of suspended and dissolved solids might be harmful to aquatic life. In the present study of Lakshmital a marked spatial and temporal variation has been observed in total solids with a range of 675.33 to 1114.77 mg/l irrespective of sites and seasons. Maximum amount of total solids were reported in the region adjacent to boundary wall followed by sewage inflow site. Naik *et al.*, (1996) recorded much higher range of total solids varying from 290 to 530 mg/l and 243 to 325 mg/l respectively in Amarnath and Tilaknagar pond in Rourkela.

Maximum TDS were obtained during post-monsoon season followed by pre-monsoon and winter seasons. Results suggest that increase in total solids during post-monsoon season may be attributable to the contribution of domestic sewage, increase effects of soil erosion and surface run off, weathering of watershed region by rainfall and surface run-off of high intensity.

*Total suspended solids* denote the suspended impurities present in the water. In most of the cases they are organic in nature and possess severe problems of water pollution (Trivedi *et al.*, 1987). Region adjacent to boundary wall exhibited maximum TSS (356.00 mg/l) followed by sewage inflow site and watershed region. Runoff generally increases the TSS in aquatic bodies. The global most natural concentration of TSS in the fresh water ranging from 3.0 to 15.0 mg/l (Mayback *et al.*, 1989). Kiran *et al.* (1999) recorded a high range of

TSS (52.2 – 278.3 mg/l) in the wetlands of Bangalore, as a result of silt and suspended nutrients. Tripathi *et al.* (1999) in Gavinath pond (150 to 529 mg/l), Chandrashekar *et al.* (2003) in Bellandur lake (100-125 mg/l), Ramachandra *et al.* (2002) in Varthur lake and Deswal *et al.* (2006) in Brahm Sarovar, support the present findings with a high concentration of total suspended solids. Similar seasonal pattern has been observed for suspended solids as total solids.

During winter season Total Suspended Solids (TSS) had significant positive correlation with fluoride and iron whereas in pre-monsoon and post-monsoon seasons it showed significant positive relation with fluoride and potassium respectively. In the present study positive correlation of TSS with fluoride and potassium was due to their geogenic origin that elevated the quantity of TSS in lake water. During all seasons a significant negative correlation was observed between TSS and calcium that was due to the calcium being principal contributing cation to hardness (Saxena *et al.*, 1989) and on contrary, TSS contributed to turbidity.

*Total dissolved solids* are the measure of total contents of both organic and, inorganic materials present in the sample (Ramalingam, 2004). Their formation takes place due to soluble materials mixing into the water. The principle constituents of TDS are C, Mg, Na, bicarbonates, chloride and sulphate. Alabaster *et al.* (1980) reported that TDS levels in excess to 1200 mg/l are unlikely to support good fresh water fisheries. In the present study TDS ranged from 502.44 to 758.77, irrespective of all sites and seasons. Maximum concentration of TDS was observed in the region adjacent to the boundary wall as following the trend of total suspended solids and total solids. This finding also confirms the works done by Tripathi *et al.* (1999), Dwivedi *et al.* (2005), Chattopadhyay *et al.* (2002), Rao (2001) and Ramalingm (2004). On contrary, Ismail *et al.* (2005) in tropical freshwater wetlands, Perak and Kiran *et al.* in

Bannergatta and Sankey lakes reported low levels of TDS that showed the less polluted status of the water bodies. Seasonally the TDS values were high during post-monsoon season and relatively low in other seasons. Since dissolved solids are a part of total solids, therefore, same interpretations can be drawn as were for total solids. The present study supports the findings made by Nayak (1980) and Rudezyk *et al.* (2002). The concentration of TDS in the Lakshmital exceeded the permissible limit, 500 mg/l (ICMR, 1975; ISI, 1992; USEPA, 1989).

During winter season and post-monsoon season total dissolved solids showed significant positive correlation with iron and potassium respectively. This relation could be explained by the persistence of both the contents in dissolved form in the water that elevated the TDS level in the lake because during post-monsoon season highest potassium concentration was recorded. A significant negative correlation was obtained between TDS and calcium in post-monsoon season.

The *total hardness* of water is the sum of concentration of alkaline earth metal cations present in it. Calcium and magnesium are the principal cations imparting hardness; however, to lesser extent cations like iron, magnesium and strontium are also responsible for it (Saxena, 1989). The hardness of water reflects the nature of geologic formation with which the water is in contact. This is the property of water, which prevents lather formation with soap and produces scale in hot water system. There was no significant variation in total hardness contents with respect to sampling sites within Lakshmital. Minimum hardness was recorded in the region adjacent to boundary wall. The values did not exceed the permissible limits that were 300 mg/l sets by ISI (1992) and 500 mg/l by UNEP (1991) and WHO (1998). Similar results were obtained by Jha *et al.* (2002). However Tripathi *et al.* (1999), Chattopadhyay *et al.* (2002),

Ramlingam *et al.* (2004) and Deswal *et al.* (2006) found hardness much higher than Lakshmital. Maximum hardness was recorded in pre-monsoon season followed by winter and post-monsoon season because hardness remains minimum in high flow seasons and maximum in lean seasons (Gautam, 1990). Gengerke *et al.* (1972) reported a decreasing trend in hardness from May to September in South Dakota Farm pond. This finding also confirms the works of Nayak (1980) and Patel (1995). On contrary, Das *et al.* (2007) recorded a different trend in total hardness.

Among all sites well water near Kali temple exhibited the maximum hardness that was found slight above the permissible limits for drinking water that can be attributed to the geologic formation of the base rock of well. Limestone and dolomite are the major source of calcium and magnesium concentration in the catchment areas (Zutshi *et al.*, 1989).

In pre-monsoon and post-monsoon seasons total hardness exhibited a significant negative correlation with potassium because total hardness was the highest in pre-monsoon season while potassium imparted to softness. A significant positive correlation of total hardness was obtained between sodium and sulphate that might be attributed to geogenic origin of both of them. Chattopadhyay *et al.* (2005) observed high correlation coefficients between total hardness and calcium ($r = 0.99$) and total hardness and magnesium ($r = 0.71$) in winter season.

*Calcium* is found in great abundance in all natural waters and its source lies in the rocks from which it is leached. Its concentration varies greatly in natural waters depending upon the nature of the basin. It is an important micronutrient that plays an important role in the biological productivity of lakes and ponds (Ellis *et al.*, 1948) and principal contributing cation to hardness (Saxena *et al.*,

1989). In the present, calcium varied from 82.33 to 94.44 mg/l within the Lakshmital lake that showed insignificant variation within the sampling sites. Maximum concentration was recorded on sewage inflow site due to decomposition of high amount of algae and phytoplankton present on the side that leaded to calcium accumulation. The calcium values in the lake were found within permissible limits (100 mg/l) guided by WHO (1971). Similar results were reported by Muri *et al.* (2004) in three Slovenian mountain lakes while, Babar *et al.* (2007), Gengerke *et al.* (1972), Tripathi *et al.* (1999), Ramalingam (2004) and Sublette *et al.* (1967) obtained much higher calcium values. Calcium was exhibited maximum during pre-monsoon season followed by winter and post-monsoon seasons. This may be due to enrichment of $CO_2$ by increased decomposition and respiration activity that shifts the carbonate equilibrium and consequently, $CaCO_3$ is redissolved from the water and sediment leading to rise in calcium concentrations (Muri, 2003). Blue-green algae during midsummer noted for depositing lime (Welch, 1952). High pH values during summer may also have caused precipitation of $CaCO_3$ from solution because this substance is less soluble at increased pH level. Gengerke *et al.* (1972) in South Dakota Farm pond reported similar seasonal variation.

During winter season calcium exhibited the significant positive correlation with sulphate because calcium is a cation and sulphate is an anion and both of them have natural origin and contribute to hardness in the water. In pre-monsoon and mean annual calcium had significant positive correlation with dissolved oxygen that can be explained as calcium was an important micronutrient that played an important role in the biological productivity of lakes and ponds (Ellis *et al.*, 1948) and increased number of phytoplankton that release oxygen during photosynthesis activity. During different seasons a significant negative correlation of calcium with potassium, fluoride, iron and ammonia was reported because potassium is an important macronutrient that imparts softness in

contrast to hardness caused by calcium. In case of ammonia, calcium has natural origin while ammonia is the end product of decomposition activity of organic waste. The fluoride and iron contributed to total suspended solids that increased turbidity in contrast to hardness.

In well waters, well near Kali temple exhibited the maximum calcium concentration that exceeded the permissible limits of drinking water quality standards for calcium. As it is a part of total hardness, same interpretations can be drawn.

*Magnesium* concentration depends on the rock type of the catchment and it is generally in low concentration than calcium. Magnesium is a necessary constituent of chlorophyll without which no ecosystem could operate (Saxena, 1989). The demands of magnesium in metabolism are minor in comparison to quantities generally available in freshwaters (Wetzel, 2001). In Lakshmital magnesium varied from 43.66 to 56.22 mg/l that showed insignificant variation within sampling sites. The value was reported within permissible limits (150 mg/l), suggested by WHO, 1971. Maximum concentration was exhibited in the area adjacent to vegetable farms because of the presence of higher water level and characteristic of magnesium concentration, relatively conservative and fluctuating little. Low metabolism at the site may also be a cause of higher magnesium concentration. Muri *et al.* (2003) depicted low concentration of magnesium in 14 Slovenian Mountain lakes. Ramalingam (2004) also supports the present finding. On the other side, higher concentration of magnesium was exhibited by Tripathi *et al.* (1999) and Babar *et al.* (2007). Same seasonal pattern as for total hardness and calcium was reported for magnesium, as it is a counterpart of calcium and contributor to hardness of water.

In well water same results were obtained as for total hardness and calcium.

During pre-monsoon and post-monsoon seasons and in annual mean; magnesium showed significant negative correlation with ammonia and iron. In case of ammonia, it is a major end product of bacterial decomposition of organic matter while magnesium is a necessary constituent of chlorophyll without which no ecosystem can operate (Saxena, 1989). Iron considered being quantitatively the most important trace metal for autotrophs whereas the demand of magnesium in metabolism was minor in comparison to quantities generally available in freshwaters (Wetzel, 2001).

*Alkalinity* of water is its capacity to neutralize a strong acid and is characterized by the presence of hydroxyl (OH-) ions capable of combining with hydrogen (H+) ions (Saxena, 1989). A number of bases viz, carbonates, bicarbonates, hydroxides, phosphate, nitrates, silicates, borates etc., contribute to alkalinity (Garg, 1998). Though alkalinity has no adverse effect on health but some evidences have indicated its role in heart diseases (Trivedi *et al.*, 1984). Total alkalinity within Lakshmital ranged from 511.77 to 680.66 mg/l. Middle lake region registered higher alkalinity as compared to other sites. This can be judged by an interaction between sodium, chloride, calcium carbonates and water stagnate over a long period of time in lake central region (Malu 1999, Malu *et al.* 1998 and Musaddiq *et al.* 2001). Alikunhi (1957) stated that in highly productive waters, the alkalinity ought to be over 100 ppm. Srivastava *et al.* (2003), Pandey *et al.* (1993), Chandrashaker *et al.* (2003), Babar *et al.* (2007) and Ramalingam (2004) observed higher amounts of total alkalinity; the statement supports the findings of present study. On contrary, Barker *et al.* (1976) in Lake Pupuke and Deswal *et al.* (2006) in a study of Brahm Sarovar Lake recorded very low range of alkalinity. Post-monsoon season showed higher alkalinity as compared to pre-monsoon and winter season that could be attributed to input of a number of bases with the surface run-off and increase

amount of the inorganic carbon in the system by photosynthesis and respiration activities. Jha *et al.* (2002) supports the present study. However, a different seasonal pattern has been recorded by Deswal *et al.* (2006).

In well water same pattern as for total hardness, calcium and magnesium was reported.

During winter pre-monsoon and post-monsoon seasons, total alkalinity exhibited positive correlations with sulphate, sodium and chloride respectively that might be attributed to their contribution to alkalinity. In pre-monsoon season and mean annual, total alkalinity had significant negative correlation with iron because iron was the most important trace metal for autotrophs. According to the study carried out by Jha *et al.* (2003) on Lake Mirik, total alkalinity showed a strong negative correlation with pH and dissolved oxygen but a strong positive correlation with chloride. Muri (2004) observed strong positive correlation between alkalinity and calcium in 14 Slovenian Mountain Lakes.

*Chloride* is a salt compound resulting from the combination of chlorine gas and a metal. Munawar (1970) suggested that higher concentration of chloride in the water is an index of pollution of animal origin and there is direct relation between chloride concentration and pollution level. In the present study chloride content, in the Lakshmital varied from 105.00 to 150.26 mg/l. Maximum concentration was observed in the area adjacent to vegetable farm that clearly indicated the water is being influenced by the quantum of the chloride containing wastes entering from catchment area. The source of chloride in the place of investigation can be attributed to human origin i.e. lake dwellers (Munawar, 1971). Although the observed chloride values fall well within the permissible limits (250mg/l) suggested by ISI (1992), WHO (1988)

and USEPA (1989). Almost similar results were obtained by Tripathi *et al.* (1999), Muri *et al.* (2003), Jha *et al.* (2003), Gengerke *et al.* (1972) and Sublette *et al.* (1967) in different lakes and natural ponds. However, high levels of chloride were recorded by Ramalingam (2004), Chattopadhyay *et al.* (2002), and Babar *et al.* (2007). Decreased chloride contents observed during post-monsoon and winter seasons may be attributed to the flood conditions, dilution of water and low amount of organic waste of animal origin during the season, while in pre-monsoon season increased chloride concentration could be due to maximum growth of phytoplankton, zooplankton and bottom biota (Verma *et al.* 1970) that precipitated the chloride contents and also due to low water level and constant inflow of sewage. According to Sreenivasan (1965), Sarkar *et al.* (1964), low chloride values (less than 100 mg/l) indicate the purity of water but higher concentration in natural water denotes pollution. Gillison *et al.* (1983) used chloride to trace pollution from septic system.

Well water same as in Total hardness, calcium and magnesium.

Chloride depicted a significant negative correlation with chemical oxygen demand during winter season because high concentration of chloride in the water was an index of pollution of animal origin (Munawar, 1970) and chemical oxygen demand was amount of oxygen needed in oxidation of organic matter in the water by a strong chemical oxidant. However, in pre-monsoon and post-monsoon seasons it showed significant negative correlations with potassium and phosphate respectively that could be attributed to chloride as a salt compound that imparted to hardness while potassium and phosphate were essential nutrients for plant growth. A significant positive correlation was obtained between chloride and sulphate because both the components contributed to hardness. Muri (2004) reported significant positive correlation of chloride with sodium, potassium and calcium in a study of 14 Slovenian

Mountain Lakes. According to a study carried out by Chattopadhyay *et al.* (2005), high correlation coefficients were recorded between chloride and calcium ($r = 0.97$), chloride and total hardness ($r = 0.95$) and, chloride and total dissolved solids ($r = 0.90$) in winter season.

*Fluorides* are more common in ground waters than in surface waters. The main sources of fluoride in water are different fluoride bearing rocks. Higher amount of fluoride in water causes mottling of teeth, skeletal fluorosis, forward bending of vertebral column, deformation of knee joints and other parts of the body, and even paralysis (Saxena, 1989). In the present study fluoride contents in the lake were recorded between 1.16 to 2.64 mg/l that were found slight above the permissible limit (1.5 mg/l) of fluoride recommended by WHO. Maximum concentration was obtained in the central region site that might be due to low human interference because origin of fluoride occurs from natural rocks. Tripathi *et al.* (1999) in Gavinath pond reported similar results. Winter season showed the maximum concentration followed by post-monsoon and pre-monsoon seasons that can be judged by low dilution of water during winter as compared to other seasons that caused the increase in concentration of fluoride contents in the water.

In well waters; the fluoride concentration was observed within the permissible limits for drinking water, recommended by WHO.

*Phosphorus* plays a significant role in biological metabolism, but is present only in very small amount in the hydrosphere (Wetzel, 1975). Bottom sediments of lakes and ponds recognized the source of higher concentration of phosphorus in water body (Olsen, 1958, 1964; Holden, 1961). The increased application of fertilizers in agricultural field, by use of detergents, domestic sewage and surface run-off from agricultural field greatly affect the heavy

loading of phosphorus in the lakes and ponds (Golterman, 1975). This accelerates the rate of productivity and causes eutrophication (Vollenwider, 1968; Schindler *et al.*, 1971). If, other nutrients are available, one pound of phosphorus can produce 500 pounds of algae (Wetzel, 1983). Phosphates are formed from the phosphorus element. Phosphates exist in three forms: orthophosphate, metaphophate and organically bound phosphate. Organic phosphates are important in nature; their occurrence may result from breakdown of organic pesticides, which contain phosphates. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways (Kumar *et al.*, 2003). It is considered amongst the primary limiting nutrients in lakes and ponds (Schindler, 1971) that stimulate the growth of photosynthetic aquatic micro and macro organisms in nuisance quantities.

The values of phosphate observed in the present study varied significantly (0.65 to 1.54 mg/l) between different sites. Sewage inflow site showed maximum phosphate concentration due to constant input of domestic wastewater that accompanied various pollutants and nutrients with it. Phosphate contents in Lakshmital have exceeded the critical level of phosphates (0.08 mg/l) for the occurrence of eutrophication in lakes and reservoirs suggested by USEPA (1976). Different studies carried out by Kiran *et al.* (1999), Jha *et al.* (2003), Tripathi *et al.* (1999), Jain *et al.* (1996) and Rao *et al.* (2001) showed similar results to that of Lakshmital. Maximum phosphate was obtained during pre-monsoon season with a decreasing trend during post-monsoon and winter seasons that may be attributed to runoff from fertilized cropland, runoff from vegetated watersheds and other anthropogenic sources (Benoit, 1988). Increase in death and decay of vegetation and aquatic life (Cooper, 1958) because of low dissolved oxygen levels that was utilized by microorganisms in decomposition process during pre-monsoon season. Diatoms are also capable of absorbing phosphate in large quantities (Ruttner, 1953). Similar seasonal pattern was

reported by Rudezyk *et al.* (2002) and Chaudhari *et al.* (1979) in Lowland Polyhumic Dam reservoir and Hirakund dam respectively. However, a different trend was recorded by Nasar *et al.* (1974) and Nayak (1980). Moyle (1946) has characterized phosphorus fertility as index of aquatic fertility.

During winter season phosphate possessed significant positive correlation with potassium and biochemical oxygen demand that might be due to an increase in biological productivity of the lake through high concentration of phosphate in the season. In pre-monsoon and post-monsoon seasons, phosphate exhibited significant positive correlation with ammonia and potassium that was due to increased bacterial decomposition of organic matter originated by dead plants. In mean annual phosphate showed significant positive correlation with iron and sulphate because potassium, iron and sulphate, all were important nutrients for plant growth in the lake at micro and macro levels. Only in winter season phosphate showed significant negative correlation with dissolved oxygen because dissolved oxygen is reciprocal to biochemical oxygen demand that had positive relation with phosphate. In a study conducted by Chattopadhyay *et al.* (2005), correlation coefficients were high between phosphate and nitrate ($r = 0.84$) and phosphate and total dissolved solids in winter season while in pre-monsoon season, a weak negative correlation was observed between phosphate and total suspended solids.

*Nitrates* are naturally occurring ion that is part of nitrogen cycle. It is one of the major inorganic salts as regulating to productivity; seasonal abundance of phytoplankton could be correlated with the seasonal changes in the availability of these salts. So nitrate is considered to be the major limiting nutrients (Hutchinson, 1975). Nitrate concentration depends on the source of water and nature of the catchment of a water body (Sahai *et al.*, 1969; Senayya *et al.*, 1979). The raw sewage is the source of nitrates and phosphates in water

(Aggarwal *et al.*, 2000). It can be reduced by bacterial denitrification. In the present study a wide variation (0.39 to 8.69 mg/l) has been exhibited between sites of Lakshmital that exceeded the standard of nitrate concentration for inland surface water 0.1 mg/l recommended by NEERI, 1988. Maximum concentration has been observed at site adjacent to vegetable farms that may be attributed to the leaching of nutrients from fertilized croplands and input of plant residues with runoff from vegetated watersheds (Hemond *et al.*, 1988). Present findings confirm the results obtained by Tripathi *et al.* (1999), Chatterje (1992), Kaur *et al.* (1996), Muri *et al.* (2004), Jha *et al.* (2003), Dixit *et al.* (2005), Rao (2001), Ramalingam (2004) and Deswal *et al.* (2006).

Maximum nitrate contents were recorded during post-monsoon season as compared to winter and pre-monsoon season. Sugunan (1995) reported the same seasonal variation in Govind Sagar reservoir, where the highest concentrations of the nutrients were recorded after rains, probably by transport of nutrients from watershed areas with the runoff water. Active biological process influenced by organic pollution is also one of the reasons (Mc Neely *et al.*, 1978). Barker (1970) also found similar seasonal variation in nitrate with a high of 0.27 mg/l in post-monsoon, to a minimum of 0.09 mg/l during summer depletion in, but rose to 0.27 mg/l again in winter.

In pre-monsoon season nitrate showed significant negative correlation with ammonia because nitrates were naturally occurring ion that was a part of nitrogen cycle and major limiting nutrients whereas ammonia was important animal excretory product and easily used form of nitrogen. In mean annual a significant negative correlation was observed between nitrate and dissolved oxygen that might be due to consumption of dissolved oxygen by fast growing algal blooms with the increased concentration of nitrate in the lake. Muri (2004) in a study of 14 Slovenian Mountain Lakes recorded a significant positive

correlation of nitrate with sulphate. In a study conducted by Chattopadhyay *et al.* (2005) a high correlation coefficient was reported between nitrate and total suspended solids (r = 0.86) in winter season whereas in June nitrate recorded the highest correlation value with total dissolved solids (r = 0.96) followed by total hardness (r = 0.80). A study carried out by Kumari *et al.* (2007) established a significant positive correlation between nitrate and phosphate.

*Sodium* ranks sixth among the elements in the order of abundance. This cation occurs generally in lower concentration than calcium and magnesium in fresh waters, and makes its way in water through weathering of rocks. Its presence indicates lake pollution caused by human activities, high concentration of sodium can harm soil permeability often associated with chloride. Its salts are highly soluble in water and impart softness (in contrast to hardness) (Saxena, 1989). They are found in ionic form in plant matter. In Lakshmital sodium concentration varied between 102.44 to 173.66 mg/l that lie within recommended desirable limit (200 mg/l) in most natural water bodies. The concentration was found much higher than the values obtained by Muri *et al.* (2004) in 14 Slovenian Mountain lakes(0.5 to 1 mg/l) and sodium concentration in Lotus lake (3.0 mg/l) (LPL, 2005). However, Rao(2001) in Kolleru lake region and Ramalingam (2004) in Velachery lake obtained higher concentration of sodium. Maximum value was obtained in the area adjacent to boundary wall followed by area near vegetable farms that may be due to higher anthropogenic interference within the sites and high pollution concentration coming out from road salt, fertilized, and human and animal waste. Seasonally maximum sodium was observed during post-monsoon season with a decreasing trend during pre-monsoon and winter months that may be attributed to deposition of silts, salts and other dissolved solids during rains with surface run-off, run-off from fertilized cropland and run-off from watershed area; and also due to lower photosynthetic activity during the season. Ramachandra *et al.* (2002) also

reported the similar seasonal pattern in Varthur Lake. On contrary, Rudezyk *et al.* (2002) recorded maximum sodium value (7.44 mg/l) in pre-monsoon season followed by post-monsoon and winter seasons.

In well waters; a very high range of sodium was observed that indicated saline nature of water. It may be due to presence of natural salts in wells and geologic formation of base rock of well.

*Potassium* occurs in natural waters in far lesser concentration than calcium, magnesium and sodium. It behaves in the water as does sodium. Though found in small amounts, it plays a vital role in the metabolism of freshwater environments and considered to be an important macronutrient. Salts of potassium are highly soluble in water and readily incorporated into the mineral structure and accumulated by aquatic biota as it is an essential nutritional element (Kumar *et al., 2003*). In the present study potassium ranged between 22.00 and 37.33 mg/l i.e. higher than the potassium level (10 mg/l) found in natural water generally. Maximum potassium was exhibited in middle of the lake. Ramalingam (2004) reported similar range of potassium in Velachery Lake. On contrary, a very low concentration of potassium was recorded in Lotus Lake (LPL, 2005). Post-monsoon season showed the highest potassium values followed by pre-monsoon and winter seasons. Increased level in post-monsoon may be due to the abundance of fertilizers and animal waste with surface run-offs and potassium salts from watershed run-off. In other seasons low amount was found due to resistant to weathering of rocks relatively and higher evaporation rate. Ramachandra *et al.* (2002) also reported elevated levels of potassium in post-monsoon season.

In well waters; potassium was reported within the desirable amount (20 mg/l) in drinking water.

*Ammonia* is a major end product of bacterial decomposition of organic matter and is important animal excretory product (Wetzel, 1983). It is directly available for plant growth and is most easily used form of nitrogen. It can support the rapid development of algal blooms if other nutrients are present. Higher concentration of ammonia is harmful to fish and other biota and even to human beings. In Lakshmital ammonia depicted a variation between 0.06 to 2.64 mg/l at different sites i.e. higher than the permissible limit (0.5 ppm) recommended by WHO. Sewage inflow site exhibited the highest concentration of ammonia because of high rate of decomposition at the site. The work done by Muri *et al.* (2003) in three Slovenian Mountain lakes and Das *et al.* (2007) in three tropical water reservoirs in Eastern India and Generke *et al.* (1972) reported results similar to present study while Jha *et al.* (2003) recorded a low range of ammonia (0.006 to 0.072 mg/l) in lake Mirik due to the fact that aquatic autotrophs rapidly utilize ammonium ions preferring those to nitrates. Seasonally maximum ammonia values were observed in pre-monsoon period that may be attributed due to low water and constant inflow of sewage and other kind of wastes into the lake; and high rate of bacterial decomposition of dead plants, animals and also major excretory product of aquatic animals. In post-monsoon and winter seasons, relatively low concentration of ammonia was recorded. Ramalingam (2004) also reported the highest ammonia during pre-monsoon season that confirms the results of present study. On contrary, Ramachandra *et al.* (2002) found maximum ammonia concentration in the post-monsoon season.

*Iron* in water may be present in varying quantities depending upon the geology of the area and other chemical components of the waterway. Ferrous ($Fe^{2+}$) and ferric ($Fe^{3+}$) ions are the primary forms of concern in the aquatic environment. Other forms may be either organic or inorganic wastewater streams. Ferric ion is an important plant nutrient and considered to be quantitatively the most

important trace metal for autotrophs because of its indispensability for many enzymes and redox processes. Some microorganisms (like creaothrix) are capable of utilizing dissolved iron (ferrous state) as an energy source and convert ferrous into ferric hydroxide. (Saxena, 1989). In the present study iron varied from 0.24 to 2.09 mg/l in Lakshmital that was found above the permissible limit (0.1 ppm), recommended by WHO. Watershed region exhibited maximum concentration that may be due to input of iron in the lake with run-off coming from watershed area accompanying weathered material with it and interference by human activities. Singh *et al.* recorded very high range (431-1407 mg/l) of iron in natural lakes of Nainital. Maximum iron contents were found during pre-monsoon season followed by winter and post-monsoon seasons that can be related to human settlements, agricultural activities and increased diffusion of ferrous iron from the sediment at lower concentration near the sediment surface. Singh *et al.* (2006) confirms the findings of present study by reporting the highest concentration of iron in pre-monsoon season.

*Sulphate* ion is one of the major anions occurring in natural waters, particularly high in arid and semi-arid regions where natural waters in general have high salt content. Sources of sulphate include minerals found in the watershed, acid rain from industrial output, domestic waste and sewage. Sulphate salts are mostly soluble in water and impart hardness. In Lakshmital sulphate contents were found between 23.77 and 33.66 mg/l that fall well within permissible limits (400 ppm) suggested by WHO. Middle lake region showed the highest value of sulphate that may be due to rock base type of the aquatic body. Almost similar results were obtained by other workers viz. Tripathi *et al.* (1999), Muri *et al.* (2003), Gengerke *et al.* (1972). Babar *et al.* (2007), Rao (2001) and Ramalingam (2004), in various natural lakes and ponds. Seasonal observation revealed maximum sulphate during pre-monsoon season followed by post-

monsoon and winter seasons. This may be due to metabolism of increased organic matter by constant input of domestic waste and sewage.

*Dissolved oxygen* in water, often referred to as DO, is a very important parameter of water quality and is an index of physical and biological processes going on in water. There are two main sources of DO in water; (i) diffusion from air, and (ii) photosynthetic activity within water. Diffusion of oxygen from air to water is a physical phenomenon and depends upon solubility of oxygen which, in turn, is influenced by factors like temperature, water movements and salinity etc. Photosynthetic activity is a biological phenomenon carried out by autotrophs (mainly phytoplankton in water) and depends upon autotroph population, light conditions, and available gases etc (Saxena, 1989). DO is essential to the metabolism of all aquatic organisms that possess aerobic respiratory biochemistry (Wetzel, 1975). According to Edmondson (1966) DO changes in water column are reliable parameter in assessing trophic status and the magnitude of eutrophication. The low level of DO content might be attributed to the respiratory activity of the fauna and flora in the lake (Odum, 1971). Further the cloudy weather that prevails on the rainy days adversely affects the primary productivity, resulting in the reduced oxygen concentration (Odum, 1971).

In the present study higher oxygen concentrations have been reported during winter months while minimum values have been observed during pre-monsoon season. All sampling sites located in peripheral region, and in contact with high anthropogenic activities showed lesser amount of DO, whereas higher contents have been estimated at the middle of the lake. The obtained results are below the recommended DO concentration for a healthy and ideally productive lake water body i.e. 8 mg/l (Wetzel, 1973). These results are in accordance to Hussainy (1967), Moitra *et al.* (1968), Vyas (1968), Khare (1978), Rosas *et al.*

(1985) and Jain *et al.* (1995). In recent past Tripathi *et al.* (1999) recorded similar observations in Gavinath pond, where DO contents varied from 1.40 to 1.86 mg/l, Rao (2001) in Kolleru lake (2.9 to 4.6 mg/l), Ramalingam (2004) in Velachery lake (1.4 to 6.2 mg/l) and Deswal *et al.* (2006) in Brahm Sarovar (5.3 to 6.3 mg/l). On contrary, Pandey *et al.* (2001), Jha *et al.* (2003) and Wanganeo *et al.* (1997) reported higher concentrations of oxygen in different lakes. The seasonal fluctuations in the dissolved oxygen can be correlated with temperature which influences the oxygen solubility in water (Zutshi *et al.*, 1978). At high temperature, the solubility of oxygen decreases while at low temperature it increases (Plimmer, 1978). Consumption of oxygen through organic matter degradation and oxidation of inorganic waste in the water column could be the other reasons of low DO level. However, low temperature and aeration rate during winter was possibly responsible for increased amount of dissolved oxygen.

A significant negative correlation was found between dissolved oxygen and chemical oxygen demand during post-monsoon season because chemical oxygen demand was the rate of removal of oxygen in chemical reactions in the lake. Kumari *et al.* (2007) observed a high significant positive correlation ($r = 0.937$) between dissolved oxygen and nitrate in two Tropical Model Ponds on India

The rate of removal (i.e. consumption) of oxygen by microorganisms in aerobic degradation of the dissolved or even particulate organic matter in water is called *biochemical oxygen demand (BOD)* and it is used as an index of organic pollution in water. More the oxidizable organic matter present in water, more the amount of oxygen required to degrade it biologically, hence more the BOD (Saxena, 1989). More *et al.* (1976) reported that it has been a very fair measure of cleanliness of any water on the basis that values of less than 1-2 mg/l are

clean. 3 mg/l fairly clean, 5 mg/l doubtful and 10 mg/l definitely bad and polluted. In the present study results showed that BOD was highest during pre-monsoon season followed by post-monsoon and winter seasons. But significantly all the values exceeded the permissible limit (1 mg/l) throughout the study period. Statistically, the BOD values differed significantly with respect to sampling sites of Lakshmital. Sewage inflow site and outflow of the lake exhibited the higher BOD values, whereas lower values were recorded in the central lake region. This may be attributed to presence of excessive nutrients such as nitrates and phosphates commonly originate in domestic sewage, runoff from domestic fertilizers, waste material form animal feed lots, etc. These nutrients, as pollutants, stimulate the growth of microorganisms, which often increase the BOD (Tripathi *et al.*, 1999). The results obtained by Rao (2001), Deswal *et al.* (2006), Tripahi *et al.* (1999) in different ponds and lakes support the findings of present study with a high range of BOD. On, contrary, Babar *et al.*, (200&) exhibited a very low range (0.2 to 0.7 mg/l) of BOD in Lonar lake, due to low rate of primary production in aquatic ecosystem of the lake. Ramalingam (2004) also reported same seasonal pattern that in BOD determination. During summer months the BOD value was found to be high, due to high temperature, pH and the presence of microorganisms, which easily degrade the organic matter in the presence of oxygen. The high BOD values may be attributed to community activities from nearby residential areas.

*The chemical oxygen demand (COD)* measures the organic portion susceptible to oxidation by strong chemical oxidant, usually potassium dichromate (Hancock, 1984). However it is sometimes used to indicate the total organic matter presents (Steel *et al.*, 1979). In present study COD varied between 7.69 to 958.29 mg/l, irrespective of all sites and seasons. Highest COD value was recorded in the lake region adjacent to vegetable farms followed by the area near boundary wall. All the values are much higher than the recommended

value of COD (20 mg/l) guided by CPCB and WHO. Tripathi *et al.* (1999) in Gavinath pond (28.12 to 39.25 mg/l), Chattopadhyay *et al.* (2002) in East Calcutta wetland ecosystem (80-15111 mg/l) and Rao (2001) in Kolleru lake (81 to 192 mg/l) recorded the similar observations to the present study. However, Babar *et al.*, 2007 in Lonar Lake found very low COD range (0.01 to 0.04 mg/l). Seasonally COD showed a similar trend as of BOD, therefore, same interpretations can be drawn as were for BOD.

# Discussion

## (B) Metals Concentration

Trace elements, and especially so-called heavy metals, are among the most common environmental pollutants, and their occurrence in waters, sediments and biota indicates the presence of natural or anthropogenic sources (Forstner *et al.* 1979). Heavy metals are metals having a density of 5 g/cc, (Nies et al., 1999). These metals include elements such as copper, cadmium, lead, selenium, arsenic, mercury and chromium etc. The main natural source of trace elements is weathering of minerals; industrial effluents are the non-point pollution sources, as well as atmospheric precipitation (Salomon et al., 1984). Currently, anthropogenic inputs of metals have exceeded natural sources. Although heavy metals are essential component of the system that are required for growth and development of plants and animals but their higher concentration is toxic to biota and water user life forms (Parashar et al., 2003). Metal concentrations in the water column and the sediments of a water body determine the quality of water (Saikia et al., 1988). However, concentrations of metals and their impacts can be greatly modified due to interaction with natural water ingredients (Pettersen et al. 1993). Therefore, knowledge of the concentrations of trace elements is desirable for the estimation of pollution levels of waters and the determination of background values of metal concentrations in corresponding regions. The water, sediments and plants in wetlands receiving urban runoff contain higher levels of heavy metals than wetlands not receiving urban runoff (Maharana, 2000). The effects of trace elements in an aquatic ecosystem can be assessed by changes in the community structure, physiological activity and ultrastructural components of macrophytes (Chester et al., 1974; Bohn, 1975; Pulich et al., 1976; Bradford, 1976). High levels of Cd, Cu, Pb, Fe can act as

ecological toxins in aquatic and terrestrial ecosystems (Guilizzoni, 1991; Balsberg et al., 1989). Recent studies have shown the bioaccumulation and biomagnification of different toxic metals in the wetland environment of India (Sharma et al., 1990; Saxena et al., 1991; Fender et al., 1992; Madhappan, 1993; Rao et al., 1993; Mehta et al., 1996; Sharma et al., 1996; Rema et al., 1997; Thaker et al., 1997). Cairns et al. (1994) estimated the effects of toxicants on ecosystem services.

## Metals in water

*Cadmium (Cd)* is one of the most toxic heavy metals and is considered non-essential for living organisms (Holan, 1994). Cd has been recognized for its negative effect on the environment where it accumulates throughout the food chain posing a serious threat to human health (APHA, 1998). Cd pollution has induced extremely severe effects on plants (Baszynski, 1986). Unlike it is an essential and beneficial element for human bodies and plants.

In the present study Cd concentration in Lakshmital varied from 0.001 to 0.06 mg/l irrespective of all sites that was found below permissible limit (2.0 mg/l) suggested by EPA, 1989. Maximum concentration was recorded at sewage inflow site followed by watershed region that was attributed due to constant input of sewage with domestic waste and inflow of weathered material with runoff. Chen et al. (2000) reported Cd variation from 0.001 to 0.114 μg/l in 20 lakes in the northeastern United States. Kumar et al. (2008) detected Cd concentration (1.81 ppm) in Kanewal community reservoir. Devi (2006) also recorded a low value of cadmium (0.30 μg/l) in Loktak lake while Singh et al. (2006) obtained a high range of Cd (0.7 to 2.7 μg/l) in natural lakes of Nainital.

*Chromium (Cr)* is a naturally occurring element in rocks, animals, plants, soil, and volcanic dust and gases. It occurs in the environment predominantly in one of two valence states: trivalent chromium (Cr III), which occurs naturally and is an essential nutrient, and hexavalent chromium (Cr VI), which, along with the less common metallic chromium (Cr 0), is most commonly produced by industrial processes (ATSDR, 1998). The most important industrial sources of chromium in the atmosphere are those related to ferrochrome production. Ore refining, chemical and refractory processing, cement-producing plants, automobile brake lining and catalytic converters for automobiles, leather tanneries, and chrome pigments also contribute to the atmospheric burden of chromium (USEPA, 1998). The general population is exposed to chromium (generally chromium [III]) by eating food, drinking water, and inhaling air that contains the chemical. The average daily intake from air, water, and food is estimated to be less than 0.2 to 0.4 micrograms (µg), 2.0 µg, and 60 µg, respectively.

In Lakshmital chromium was observed between a range of 0.018 to 0.22 mg/l that was reported within the permissible limits (2 mg/l) as guided by EPA, 1989. Following the trend of Cd maximum concentration was observed at sewage inflow site. Chattopadhyay et al. (2002) reported chromium concentration from 0.05 mg/l to 0.20 mg/l in the East Calcutta wetland ecosystem. Bajpai et al. (2002) found chromium in lakes of Bhopal from 0.006 mg/l to 0.022 mg/l. Parashar et al. (2003) observed Cr content in Upper Lake of Bhopal in the range of 0.034 mg/l to 0.041 mg/l. Singh et al. (2006) obtained chromium values between 0.29 µg/l and 2.39 µg/l in natural lakes of district Nainital. The above results support the findings of present study.

*Copper (Cu)* and compounds occurs naturally in the earth's crust in rocks, soil, waters, plants, animals and humans. It is also present in fresh and sea water. These are generally at low concentrations. This trace element is essential to

many plants and animals, and occurs in biological complexes such as pheophytin, hemocyanin and tyrosinase. Copper may be released as particles into the atmosphere or as dissolved compounds in water. It is also released from natural sources such as volcanoes, windblown dusts, decaying vegetation and forest fires. It usually attaches to particles of organic matter, clay, soil or sand. Copper is commonly found as copper (II) in natural waters and the free copper (II) ion is potentially very toxic to aquatic life, both acutely and chronically. Its toxicity increases with decreasing water hardness and dissolved oxygen concentration, and decreases with high concentrations of dissolved organic compounds and suspended solids. Alkalinity and pH are other factors that influence copper toxicity. Copper is expected to bioaccumulate in fish tissues. It is normally complex-bound in soil, greatly diminishing its toxicity. Copper can also be used in waterways (lakes, rivers, ponds) as an algaecide (www.npi.gov.au).

In the present study copper concentration was obtained from 0.11 mg/l to 0.69 mg/l that was much below the permissible limits (3 mg/l) as suggested by EPA (1989) for inland surface waters. The results obtained in Lakshmital for copper concentration confirms the findings of the following studies viz., Chattopadhyay et al. (2002) in the East Calcutta Wetlands (0.20 mg/l to 0.29 mg/l); Parashar et al. (2003) in the Upper Lake of Bhopal (0.015 mg/l to 0.023 mg/l); Singh et al. (2006) in natural lakes of Nainital (5.3 μg/l to 12.1 μg/l). On contrary, Kumar et al. (2008) recorded a very high concentration of copper (4.84 ppm) in Kanewal Community Reservoir.

*Manganese (Mn)* can exist in different oxidation states, from $Mn^0$ to $Mn^{4+}$. In natural waters Mn usually exists as $Mn^{2+}$ (dissolved phase) and $Mn^{4+}$ (mostly suspended phase) (Moiseenko et al., 1997). The distribution of Mn strongly depends on pH. Laboratory experiments show that a decrease of pH from 8.5 to

7.5 leads to an increase of the Mn concentration in waters by four times due to release from sediments (Delfino et al., 1971). A deficiency of oxygen in the bottom water will also lead to reduction of particulate manganese oxides, and hence an increase of the concentration of dissolved manganese.

In Lakshmital manganese concentration was recorded between 0.20 and 0.79 mg/l. The range was found below permissible limits (2 mg/l) as per recommendation of EPA (1989). Sewage inflow site followed by watershed region exhibited the highest manganese concentration. Similar studies were carried out by other workers viz., Chattopadhyay et al. (2002) in the East Calcutta Wetland (0.90 mg/l to 1.40 mg/l); Parashar et al. (2003) in Upper Lake of Bhopal where manganese was detected in the range of 0.094 mg/l to 0.234 mg/l; Singh et al. (2006) in natural lakes of Nainital (10 µg/l to 38.3 µg/l); Devi (2006) in Loktak lake (0.042 µg/l); Bajpai et al. (2002) in Upper and Lower lakes of Bhopal (0.24 mg/l to 0.326 mg/l).

In small amounts this element, *nickel*, is needed by living organisms, but in higher concentrations, it is very toxic (Sidorenko et al., 1980). In Lakshmital only two sites; sewage inflow site and watershed region exhibited very low concentration of nickel and at rest of the sites it was below detectable limits. The results obtained by Bajpai et al. (2002) supports the findings of present study with a very low value of Ni (0.014 mg/l) in Bhopal lake. Singh et al. (2006) reported 1.0 µg/l to 6.6 µg/l nickel concentration in natural lakes in Nainital. On contrary, Kumar et al. (2008) recorded a very high value of Ni (3.88 ppm) in Kanewal Community Reservoir.

*Lead (Pb)* is a toxic metal that can affect the central nervous system and other organs, if too much is consumed. The Wisconsin "action level" for lead concentration in potable water is set at 15 µg/l (or 15 ppb). The lead is more likely to be found in the lake sediments than in the liquid water column (LPL,

2005). Sources of Pb to the environment include lead-based paint, lead shot from firing ranges, contaminated food (Pb in the air or Pb-soldered food containers), drinking water in homes by corrosion of plumbing systems made of lead and lead based gasoline. Lead particles can also be carried from land to surface water by storm water runoff.

In Lakshmital lead concentration varied between 0.001 and 0.02 mg/l irrespective of all sites that was within permissible limit (0.1 mg/l) as guided by EPA (1989). Sewage inflow site exhibited the maximum lead concentration following the previous trends. At middle lake region and outflow from lake it was below detectable limits. A low amount of lead was also obtained by Singh et al. (2006) and LPL (2005) in natural lakes of Nainital (3.9 μg/l to 27.1 μg/l) and in Lotus lake (2.4 ppb) respectively that confirms the results of present study. On contrary higher lead concentrations were reported by Bajpai et al. (2002) in Bhopal lake from 0.526 mg/l to 0.648 mg/l; Chattopadhyay et al. (2002) reported lead ranged from 0.39 mg/l to 0.72 mg/l in the East Calcutta Wetland; Parashar et al. (2003) in the Upper lake of Bhopal observed lead concentration between 0.24 mg/l to 0.268 mg/l; Kumar et al. (2008) recorded a very high value of lead (6.27 ppm) in Kanewal Community Reservoir.

*Zinc (Zn)* is as essential and beneficial element for human bodies and plants. Complete exclusion of zinc is not possible due to its dual role, an essential microelement on the one hand and a toxic environmental factor on the other (Brune, 1994). However, zinc can cause nonfatal fume fever, pneumonetis, and is a potential hazard as an environmental pollutant (Hampp, 1976). Many industries, especially electroplating, battery and plastic manufacturing are the main source of zinc in waste water. In present study zinc varied from 0.17 mg/l to 0.77 mg/l within Lakshmital that was found very less range than the permissible limit (5.0 mg/l) for inland surface waters suggested by EPA, 1989 that might be due to household sewage at little extent and agricultural runoff

from surrounding areas. Regarding variation in concentration within sites previous trend was followed. Similar findings were recorded by Chattopadhyay et al. (2002) in East Calcutta Wetland (0.18 mg/l to 0.30 mg/l); Parashar et al. (2003) in Upper Lake of Bhopal (0.015 mg/l to 0.08 mg/l); Singh et al. (2006) in natural lakes of Nainital (12.6 µg/l to 166.3 µg/l) and Devi (2006) in Loktak lake (0.048 µg/l). On contrary, Kumar et al. (2008) obtained a very high value of zinc in Kanewal reservoir (201.16 mg/l).

From the above observations it was concluded that in water of Lakshmital mean manganese was detected in highest concentration followed by zinc and copper while lead and cadmium exhibited the lowest mean concentration.

## Metals in sediments

Wetland sediments are generally considered a sink for metals. Wetzel, 1975 revealed that aquatic sediment plays a critical role in the water quality modeling and nutrient cycling of the aquatic environment. In sediments heavy metals are adsorbed to clay and organic matter by electrostatic attraction (Patrick et al., 1990). Sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow, particulate size, and vegetated area of the wetland (Aust et al., 1991; Johnston 1991; Crance 1988; Hemond et al., 1988).

In the sediments of Lakshmital manganese (Mn) was observed in highest concentration followed by zinc (Zn) and copper (Cu) that might be due to inflow of household sewage with agricultural runoff from surrounding and open dumping of solid waste directly in the peripheral region of the lake. Cadmium (Cd) and lead (Pb) exhibited the lowest values because there is no direct source of industrial effluent into the lake. Nickel (Ni) was below detectable limits. Parashar et al. (2003) also reported highest concentration of manganese (207.7

mg/kg to 595.8 mg/kg) at different sites of Upper Lake of Bhopal while in rest of the metals no significant variation was detected. Similarly Singh et al. (2006) also found highest concentration of manganese (90.1µg/g to 197.5µg/g) in sediments of natural lakes of Nainital followed by lead (88.9µg/g to 167.4µg/g) and zinc (40.0µg/g to149.2 µg/g). Klavins et al. (2001) also reported a higher concentration of manganese (770µg/g) comparative to chromium and nickel in sediments of lakes in Latvia. On contrary, Chattopadhyay et al. (2002) observed higher concentration of chromium (0.13 g/kg to 49.24 g/kg) than zinc, manganese, lead and copper relatively in the sediments of East Calcutta Wetlands. Kumar et al. (2008) reported the highest concentration of zinc (1012.43 ppm) followed by cadmium (66.40 ppm), nickel (50.47 ppm) and copper (47.73 ppm) in the sediments of Kanewal Community Reservoir, those were very high values as compared to other studies.

# Discussion

## (C) Biological Characteristics

### Metals in Macrophytes

Macrophytes are considered as important component of the aquatic ecosystem not only as food source for aquatic invertebrates, but also act as an efficient accumulator of heavy metals (Devlin, 1967; Chung *et al.*, 1974). Denny (1987) recognized the following categories; emergent, surface floating, rooted leaves and submerged macrophytes. Several of the submerged, emergent and free floating aquatic macrophytes are known to accumulate and bioconcentrate heavy metals (Bryan, 1971; Chow *et al.*, 1976). Many of the aquatic macrophytes are found to be the potential scavengers of heavy metals from water and wetlands (Gulati *et al.*, 1979). Brix *et al.*, 1989; Ellis *et al.*, 1994 explained aquatic plants as biological filters of polluted waters.

Brix *et al.*, 1989; Dunbabin *et al.*, 1992; Ellis *et al.* 1994 described various examples where wetlands-utilizing aquatic plants are employed for removal of pollutants, including metals, from waters. Aquatic plants are known to accumulate metals from their environment (Outridge *et al.*, 1991) and affect metal fluxes through those ecosystems (Jackson *et al.*, 1994; St-Cyr *et al.*, 1994). Wetland plants remove small quantities of nutrients, trace metals, and other compounds from the soil water and incorporate them into plant tissue, which may later be recycled in the wetland through decomposition, stored as peat, or transported from the wetland as particulate matter (Boyt *et al.*, 1977; Tilton *et al.*, 1979; Hammer, 1992). Windham and coworkers (2004) found that submerged litter from wetland plants accumulated heavy metals in excess of

sediment concentrations. Individual wetlands have a limited capacity to absorb nutrients and differ in their ability to do so (Tiner, 1985). Odum (1988) opined macrophytes as "nutrient pumps" through their action as they play a prominent role in nutrient and heavy metal recycling of many aquatic systems (Pip *et al.*, 1992).

Ellis *et al.* 1994 opined that to improve understanding of the importance and roles of aquatic plants, we must investigate metal uptake and localization. Studies in many natural and created wetlands have found that the majority of wetland plants retain higher amounts of metals in their roots than in shoot tissue (Windom *et al.*, 1976; Breteler *et al.*; 1981; Schierup *et al.*, 1981; Peverly et al, 1995 and Keller *et al.*, 1998). Submerged rooted plants have some potential for the extraction of metals from water as well as sediments, while rootless plants extracted metals rapidly only from water (Cowgill, 1974). Denny (1980 and 1987) further noted that main route of heavy metal uptake in wetland plants was through the roots in the case of emergent and surface-floating plants, while euhydrophytes take up heavy metals through leaves and roots.

## Metal uptake in aquatic plants

In natural aquatic environments, metals may be in an available or not available form for plants to take up. It is generally assumed that free metal ions are the form primarily available to biota (Nelson *et al.*, 1985, Campbell, 1995). In the water column most metals exist as cations that are complexed to varying degrees by inorganic and organic ligands. There are a number of forms including (Borg, 1995):

- Free metal ions
- Inorganic complexes ($CO^{32-}$, $OH^-$, $Cl^-$)
- Organic complexes with fulvic and humic acids.

- Associated with colloidal and particulate materials such as clay minerals and biogenic material as living algae and detritus.

### Accumulation in plants

Higher aquatic plants may grow submersed or emergent, i. e. completely or partially below the water surface and are able to take up metals from the sediment through the root, from the water through the root and the shoot and from the air through the shoot. In addition to the uptake, there is also a release of metals back into the water and sediment from plant tissue and to the air of metals in gaseous form from the leaves. Thus, the net metal accumulation depends on both uptake into the tissue and release to the surrounding medium (Greger, 1999).

### Metal uptake in roots

The roots may penetrate into sediment, mud or wet soil, or simply remain in the free water. Metal ions are first taken up by diffusion or mass flow into the apparent free space (AFS) of the root cell walls (Marschner, 1995). Older parts of the root have hydrophobic incrustations (suberin), called the Casparian strip, in the radial cell walls (stage I) of the endodermis, which act as a barrier to the passive movement of water and solutes into the vascular cylinder (Marschner, 1995) (**Figure 6.1**).

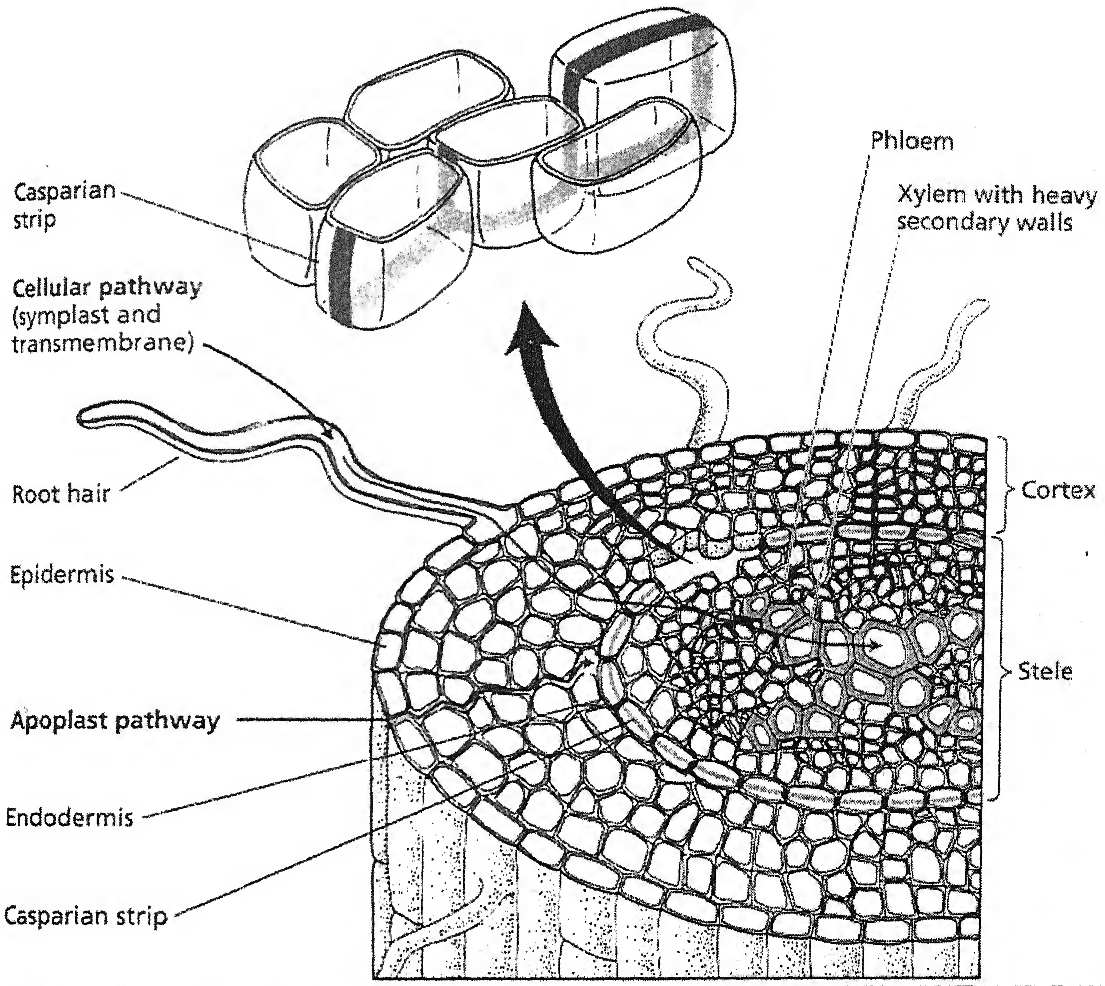



**Figure 6.1. Ion transport across the root, showing the cellular and apoplastic pathways. (after Taiz and Zeiger 1998)**

The Casparian strip can also be formed in the exodermis. Gradually the entire cell wall is suberinized (stage II). There is a certain symplastic transport of solutes across the Casparian band into the vascular cylinder, but there are different opinions as to whether this is the case for heavy metals. For this reason it may be that it primarily is metal ions that have been taken up by the tip of the root that enter the xylem and are transported to the shoot. The distance from the root tip to the Casparian strip (stage II) is larger in emersed plants. Metals that have been taken up in plant roots are bound to negative charges of

the cell wall structure, and for instance Beauford *et al.* (1977), Wierzbicka (1998) and Wang (2004) have shown that the major amount of Hg and Pb in roots is bound in the cell walls. Some of the metal is transported further within the cell walls and some is transported into the cytoplasm of the root cells (Greger, 1999) (**Figure 6.2**).

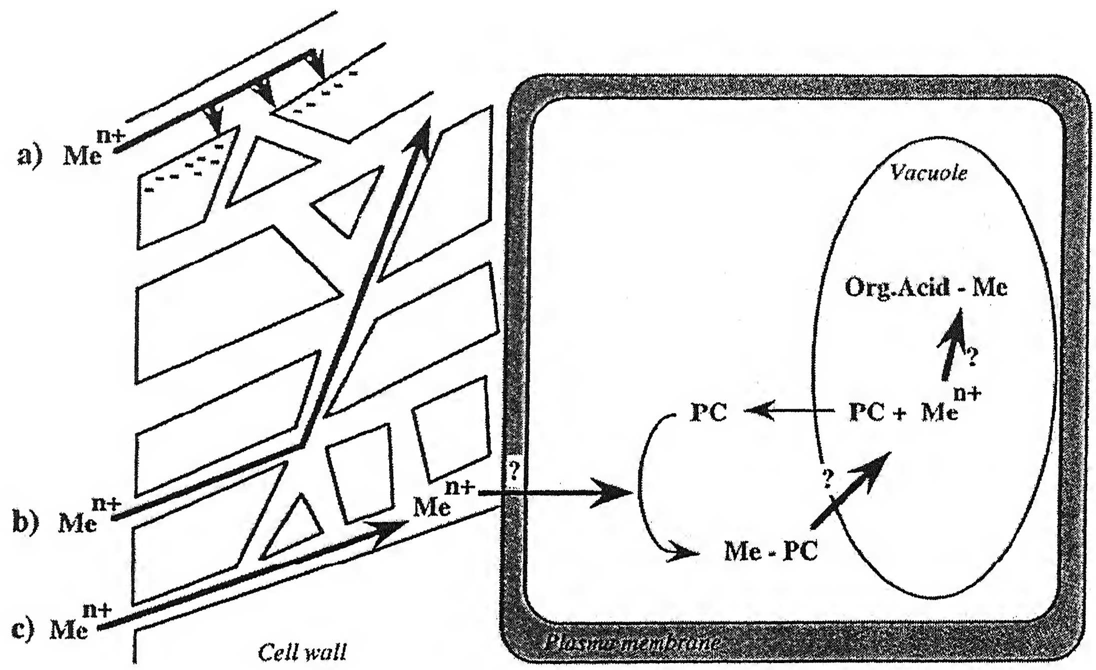



**Figure 6.2.** Schematic drawing of the uptake of metals (Me) into the root tissue. Metal ions can be: a) trapped by negative charges in the cell walls b) transported apoplastically c) transported into the cell. PC = phytochelatin. (after Greger, 1999)

## Metal uptake in plant cells

Metal ions are probably taken up into cells by membrane transport proteins designed for acquisition of nutrient metals, but not entirely specific for intended

nutrient metal (Cohen *et al.* 1998, Arazi *et al.* 1999, Fortin and Campbell 2001). In the cytoplasm, metals bind to inorganic anions, structural compounds and various macromolecules such as organic acids and sulfur-rich polypeptides, like phytochelatins (PC´s) (Grill *et al.* 1985, Prasad 1999). Synthesis of PC´s is induced by metals and they are considered to be indicators of metal stress (Gupta *et al.* 1995, 1998, Maserti *et al.* 1998, Prasad 1999). Phytochelatins may function as shuttles for transport over the tonoplast into the vacuole, where the metal is released and may be bound to an organic acid (Mathys 1977, Steffens 1990, Harmens *et al.* 1994) (Figure 5). Phytochelatin (PCs) is synthesised with glutathione as building blocks resulting in a peptide with structure Gly-(γ-Glu-Cys-)n; {where, n = 2-11}. Metallothioneins (MTs), are small gene encoded, Cys-rich polypeptides functionally equivalent to MTs (Grill, *et al.* 1987). These mechanisms, evolved for storage of micro nutrient ions, also counteract toxic concentrations of free heavy metal cations in plasmatic compartments and is a way to prevent heavy metals from interfering with sensitive metabolic reactions and from development of oxidative stress (Woolhouse 1983, Ernst *et al.* 1992). Competition for membrane transport sites and for intracellular metabolic binding sites can substantially influence the uptake of both nutrient and toxic metals and resultant effects on growth (Gothberg, 2008).

## Translocation of metals to the shoot

Some of the metal that is taken up into the root cells is transported further into the xylem vessels (**Figure 6.1**) and translocated to the shoot. How the metals are transported into the xylem is still unknown. In the xylem vessels the metals are probably translocated to some extent in complexed form but also by interactions with nondiffusible anions of the cell wall of the xylem vessels, which leads to a separation of cation transport from the water flow, as for Cd (Wolterbeek, 1987). The xylem is thought to act as an ion exchange column

that has the potential to impede the movement of the metal (Bell and Biddulph 1963). In the shoot the metal may be bound in the cell walls or transported into the cells.

## Distribution of metals in the plant

The distribution of metals between the different compartments of the cell and of the plant body depends on the metal and the plant genotype. Different plant species accumulate metals to various degrees in different parts (Guillizoni 1991, Berrow *et al.*, 1991). During their transport through the plant metals are bound largely in the cell walls, which explains why most of the metal taken up often is found in the roots and smaller amounts are translocated to the shoot (Siedlecka 1995, Greger 1999). Submersed plant species are known to translocate metals both from root to shoot and from shoot to root depending on the metal being accumulated (Eriksson *et al.*, 1975, Greger, 1999). In submersed plants about 40 % of the Cd that had been taken up in the shoot was translocated to the roots and about 20 % of the Cd that had been taken up in the roots was translocated to the shoot (Greger, 1999). On the contrary to submersed plants, terrestrial plants often have a one-way translocation of metals, from root to shoot (Greger, 1999).

In Lakshmital metal (Cd, Cu, Cr, Mn, Ni, Pb and Zn) accumulation rate was observed in four plant species viz., *Phalaris arundinacea, Potamogeton zosteriformis, Eichhornia crassipes and Elatine triandra* that are as follows:

### *Eichhornia crassipes*

Water hyacinth is a freshwater weed species. It is a free-floating plant and draws all its nutrients directly from water. Currents and wind help in its

distribution and dispersal. It comprises 95% water and 5% dry matter of which 50% is silica, 30% potassium, 15% nitrogen and 5% protein (Makhanu, 1997). It has been known to thrive well in nutrient-enriched fresh waters in tropical climatic zones. For this purpose it has been used in wastewater treatment facilities (Osumo, 2001). The focus on water hyacinth as a key step in wastewater recycling is due to the fact that it forms the central unit of a recycling engine driven by photosynthesis and therefore, the process is sustainable, energy efficient and cost efficient under wide variety of rural and urban conditions (Gijzen, 2000). *E. crassipes* collected from Lakshmital showed greater affinity towards Mn with maximum concentration (0.008 mg/g) in roots followed by leaves (0.005 mg/g). High value of Cu (0.008 mg/g) was also detected in its roots while Cr and Pb were observed in very low concentration. Cd and Ni were below detectable limits.

The present study highlights that *E. crassipes* is useful in removal of Mn. Similarly Parashar *et al.* (2003) recorded highest concentration of Mn (224.33 to 956.5 mg/kg) in *E. crassipes* followed by Pb and Zn, collected from different sites of Upper Lake of Bhopal. On contrary, Kumar *et al.* (2008) in *E. crassipes* of Kanewal reservoir obtained highest concentration of Zn (502.19 ppm) with lowest concentration of Cd (0.43 ppm). Tiwari *et al.* (2007) investigated greater affinity of *E. crassipes* towards Pb, Zn and Mn.

### *Potamogeton zosteriformis*

*P. zosteriformis* is commonly known as flatstem pondweed and it is found nearly worldwide; in ponds, lakes, 1-2.5 m deep. It is a perennial, submersed aquatic weed with fibrous roots, from slender rhizomes. Plant provides wildlife food and habitat and spreads by seeds or by creeping rhizomes.

The species collected from Lakshmital showed close affinity towards Zn with 0.030 mg/g concentration in roots followed by 0.008 mg/g in leaves. Zinc is an essential element to all plants. The mean concentration in normal plants (aboveground tissues) is 66 mg/kg (Outridge *et al.*, 1991), and the toxic level is upto 230 mg/kg (Borkert *et al.*, 1998; Long *et al.*, 2003). The value of Zn in the species was much lower than the levels reported by Outridge *et al.* (1999). Pb and Mn were exhibited low values in *P. zosteriformis*. Cd, Cr, Cu and Ni were below detectable limits. Parashar *et al.* (2003) obtained highest concentration of manganese (456.05 to 1450 mg/kg) followed by lead (19.2 to 79.9 mg/kg) and zinc (18.05 to 25.4 mg/kg). According to the present observation *P. zosteriformis* can be used for effectively for Zn contamination removal.

***Phalaris arundinacea***

*P. arundinacea* is commonly known as reed canarygrass that is frequent around lowland pools ditches and marshy areas. It is a cool season, perennial weed. Running root system form an impenetrable ground cover. The leaves of plant are used to weave into hats and mats; in some areas, the grass has been used for erosion control. Reed canarygrass reproduces mainly by rhizomes.

In *P. arundinacea* greater affinity was observed towards Cu (0.004 mg/g) and Mn (0.004 mg/g) in roots while in leaves highest concentration of Zn was exhibited. Copper is essential to plant growth, but will cause toxic effects when shoots or leaves accumulate Cu levels exceeding 20 mg/kg (Borkert *et al.*, 1998). Several authors have reported the accumulation of Cu by aquatic plant species on contaminated sites. Cardwell *et al.* (2002) investigated 15 aquatic species in Southeast Queensland, Australia; where the highest Cu in leaves of emergent plants was approximately 34 mg/kg and in uncontaminated sites, an average Cu concentration of 37 mg/kg in the aboveground tissues was recorded

(Outridge *et al.*, 1991). In present study Cu concentration was found much below than the Cu levels given by Borkert *et al.*, 1998. Cd, Ni and Pb were below detectable limits. Deng *et al.* (2004) reported metal accumulation in *P. arundinacea*, significantly in higher ratio; Pb (0.10 mg/kg), Zn (0.10 mg/kg) Cu (0.03 mg/kg) and Cd (0.06 mg/kg) in its underground tissues. According tom present study *P. arundinacea* would be a good choice for extracting Cu and Mn from a contaminated site.

### *Elatine triandra*

Elatine triandra is commonly known as small waterwort found floating in the shallow waters of lakes and ponds. The plant is a small, matted, annual herb with fibrous, unbranched, thread-like roots. Waterwort is usually considered beneficial in stabilizing shorelines. Reproduction takes place by seeds, often distributed by waterfowl.

*E. triandra* showed close affinity towards Zn. In roots it was accumulated upto 0.008 mg/g and in leaves 0.006 mg/g Zn was recorded. Cd (0.001 mg/g) and Ni (0.001 mg/g) were observed in roots at very low level while in leaves these were below detectable limits. Cadmium in normal plants is found 1.9 mg/kg (Outridge *et al.*, 1991). In present study the value of Cd showed much below concentration than the level recommended by Outridge and Noller for a normal plant. Rest of the metals was below detectable limits in *E. triandra*.

The concentration of heavy metals in different plant species indicates the affinity towards metallic ions. The accumulation in different parts of the plant relates with tendency of metallic ion to have place in particular plant tissues. Such affinity of metallic ion characterizes the particular plant species for elimination of heavy metals from the water and lake sediments and plant could

be used as biofilter media (Parashar *et al.* 2003). In Lakshmital among all the macrophytes, *Potamogeton zosteriformis* showed close affinity towards zinc with maximum concentration (0.030 mg/g) in roots with 0.008 mg/g Zn in leaves. Similarly *Elatine triandra* also showed greater affinity towards Zn. *Eichhornia crassipes* exhibited close affinity with Mn with higher concentration in roots 0.008 mg/g followed by 0.005 mg/g in its leaves. In *P. arundinacea* greater affinity was observed towards Cu (0.004 mg/g) and Mn (0.004 mg/g).

# Discussion

## (D) Socio-economic Conditions

Socio-economic survey in the peripheral region of the lake was carried out to quantify the value of wetland resources; to determine the economic dependency of the people living in the surrounding areas on these lakes as well as impact of people's activities on the lake quality.

In the *demographic information* of present study, it was normal to find most of the households were headed by men, a very few female household heads were widows or divorcees. Household size varied depending on the type of household; although more than half were small families with an average of three members. Only a few families were large families, some of them were extended with an average of ten individuals. In economic terms dependence ratio is the total number of dependent children, elderly and disabled people in a household divided by the number of working peoples. In the present study highest number of peoples belonged to middle age groups who were the main labour force of the families. On the other hand very low percentage of old peoples exhibited low dependence ratio in the region. Out of the total population interviewed, it was calculated that many of the respondents had gone through primary school education but very few got higher education. Educational levels were, therefore, low and those of the youth were higher than those of their parents.

Regarding *occupation* in the area, survey revealed that a good number of peoples were in government services at different levels e.g. accountant in Post-office, supervisor in Malaria division, inspectors, peon and sweepers etc. The

higher number of peoples was shopkeepers. The shops were of daily use commodities like general store, vegetable shops, and tire puncture repair shops etc. A very good percentage of sweepers were also residing in the area. A very few people had their own large scale business.

Occupation of the people in any area shows the socio-economic status of the residing population. In the present study half of the surveyed population was under low *income groups*, who had their annual income below fifty thousand rupees while only one fourth of the households had their annual economy in lakhs. As compared to total percentage very few peoples had their annual income above two lakh sixty thousands. Thus according to economic status of the area, it was estimated that lower class and middle class groups were in majority.

In the *water usage pattern*, all residents used water supplied by Municipal Corporation. The duration of water supply varied within the area, at some places it was twice a day while somewhere it was once a day. As an alternative source there were a number of government and private hand pumps, private borewells. Wells were also source of water supply in the region; well near Bhutnath temple was important one among them. As the majority of residents in the area belonged to low income groups, so they had low facilities like washing machines and other home appliances that increased water utilization. It was estimated that half of the households had water consumption below three hundred litres in a day and a very small percentage of people utilized water above five hundred litres per day. Water usage by livestock was low in the region because a few households had domestic animals and most of them were for their personal use. In case of irrigation water utilization except Narayan Bagh only two to three small gardens of vegetable were situated in the fringes of Lakshmital. Water of Lakshmital was used by pumps and directly for

irrigation while in lean season they had ground water as a source of irrigation water.

About the *history of the families*, survey revealed that more than half of the families were residing in the area more than ten years as well as a good percentage of households are more than thirty years old. Some of the peoples interviewed were living there since birth. Even though the opinions of the respondent vary in some way or the other in their perception of the lake, there was a general consensus among the respondent that the lake water has been degraded considerably in the last decade. Ninety-two percent of the respondents agree that the lake water was fit for drinking purposes about two decades back.

*Solid waste generation* in a particular area depends on the size of the family and living standards of the residents. Households near Lakshmital had eight kilograms solid waste generation; out of total amount near about one kilogram waste was directly thrown in the catchment of the lake. Larger part of the waste comprised of biodegradable waste with a smaller amount of non-biodegradable waste. Collection of the waste was done by government in once a week or once in fifteen days. Despite the location of the lake in the urbanized area, about ten percent households were not accessed to modern toilet facilities. Those people used periphery of the lake as open toilet which caused contamination of the water. Open disposal of waste also created unhygienic conditions in the area which caused increased number of mosquitoes and insects and destroyed the aesthetic beauty of the lake by foul odour. Thus all these activities made the lake indirect source of diseases like malaria, diarrhea and water borne diseases.

## Importance of lake

Although Lakshmi lake is under ecological crisis like other lakes in India and at present 100% of the respondent think the lake water unfit for drinking but still Lakshmital is providing economic, ecological and aesthetic values to society.

### Economic Importance

***As a source of water;*** 98% of the respondent rated water of the lake fit for animal uses. The percentage response among the resident in favour of uses of the lake water for washing cloth was 92%, irrigation purposes , it was 100% and in construction of houses, 100%. These responses showed that even though the lake is badly polluted and unfit for drinking the residents nearby still values the lake water for various other purposes.

Lakshmital is a very good source of irrigation water to its peripheral region chiefly for Narayan Bagh that comes under the State Government of U. P. It has a variety of nursery plants (like rose, mango etc.), fruit plants (like mango, guava) and flowering plants (like rose and kaner etc.). At present Narayan Bagh is source of employment for ten peoples who are working there for last ten years. The total income from the Bagh is about 4.5 lakhs/year.

***As a source of food;*** The nearby communities grow some vegetables in the peripheral area of the lake which is the source of income for them. The outlet of lake supplies water to nearby agricultural land also. The lake is also source of income for some fish sellers. Rohu, Baum and Soor are some common fish species that are found in Lakshmital. Fishing is done with the help of net and Bansi. By net at six or seven month fishing occur only one time. In a time, fish are caught about forty kilograms and total income generated are 1,400 rupees (@of 35 Rs./Kg). Seven persons remain engaged in the process of fish catch.

Sometimes people living near the taal catch fish with the help of Bansi. The main use is generally for eating but sometimes on fish occasion they sell fish in the amount of one, two or three kilograms at the rate of Rs. 60/kilograms.

***As a source of fodder;*** **Weed** and grasses in the periphery of Lakshmital is used as fodder.

## Religious and Aesthetic importance

Lakshmital is surrounded by little hillocks. Topping these hillock and around the lake there are twelve temples built in similar design, some temples in the vicinity of the taal are Mahalakmi temple, Remora temple, Mahadeo temple called Sridhar-ka-Mandir, Bhootnath Mandir, Hanuman Mandir, Anjani Mata Mandir, Mahakali Mandir and Patla Sah Hanuman Mandir. The sight of Lakshmital with the temples all around is enchanting and a reminder of the architectural skills of the builders and shows its religious importance.

Adjoining the Lakshmital there is a Narayan Bagh, famous garden of Jhansi. Any time of the day the atmosphere here is a cool peaceful and serene. There is a good collection of ornamental as well as other flowering plants in Narayan Bagh. The lake is the only source of water for this garden. During rainy season, the water level of Lakshmital becomes high so the excess water flows in Narayan Bagh directly thus it also helps extra water drainage from taal during rainy season.

Besides interview to collect information for questionnaire, some personal discussions were also carried out with the respondents about lake history and its present condition.

In a discussion with **Mr. Ram Kishore Verma**, Supervisor in Malaria Division, he explained that in 1981 the water of the lake was fit for consumption and there was no water hyacinth at that time, it grew in 1984. Before three years peoples of the area use to grow partial cultivation of cashew nut and fisheries in the lake. But at present it is used for irrigation only and no problem has risen till now by the use of this water. Residing community did not have any problem due to improper waste collection near the lake. However, some gastro-intestinal disease and malaria has occurred in the area many times. About the rehabilitation of the lake Mr. Ram Kishore told that desilting of lake had carried out various times but in lack of maintenance it went waste. Local peoples also participated in desilting of the lake. About his personal interest he replied that he would like to involve directly in the restoration of the lake.

**Mr. Ram Lal**, a resident of Radha Govind ki Bagia for last twenty six years, living with his wife only and tailor by profession told that before years people use to grow cashew nut and fisheries in the lake which had been their livelihood at that time but after degradation of the lake they got involved in other occupations. He also explained that once District Magistrate got desilting of the lake by giving some money to the local peoples but afterwards it got stopped due to money. He is also ready to cooperate in lake restoration at his level.

**Mr. R. P. Bhargav**, a government employee confirmed the previous statements of cleanliness of pond before years and production of cashew nut and fisheries in it. He also told that ground water table in peripheral colonies is higher due to lake than other region. He also stated that one District Magistrate, who is at present in Meerut, improved the condition of lake by fencing and amusements like boating in the lake. Mr. R. P. bhargav also discussed that due to unemployment, social crime has increased in last years in the area and peoples

have also encroached lake area illegally. Regarding health effects he confirmed in increase of diseases in the area like chicken guinea, viral fever and malaria.

**Mrs. Prabha,** a vegetable seller did not have any idea about the change in the water quality of the lake but she confirmed the presence of malaria and gastro-intestinal disease in the locality. She also stated that devegetation occurred several times due to overflow of the lake in the farms of vegetables. She was ready to involve in the lake restoration programme as a labour or if it would help them to improve their livelihood after purification.

**Mrs. Urmila,** thirty years old, grow vegetables and flowers in the area adjacent to lake, also confirmed that in rainy seasons overflow of lake and blocked in the drainage due to polythene waste her vegetable farms got destroyed many times. Waste vegetables are used as fodder according to her. Lake water is the source of irrigation for her farms. She also confirmed the presence of malaria in the region.

Thus by the above explanations it is concluded that lake has been in a very good condition before decade and a source of income for many of the residents but now its quality has degraded due to anthropogenic activities and lack of maintenance of the lake. But still Lakshmital with its historic, aesthetic and religious values is a source of economy for many peoples. Due to the facts local residents want to get lake restored and they themselves are ready to cooperate in the rehabilitation of the lake.

# Conclusion and Recommendations

## Conclusion

It has been concluded from the present study that increasing anthropogenic interferences due to tremendous population growth in the peripheral region of Lakshmital, subjected the lake to various environmental problems like water quality deterioration, inadequate water holding capacity due to siltation, pollution by raw sewage and solid waste dumping on the edges of lake, eutrophication by leached fertilizers and insecticides from adjacent farms and through other kind of organic pollution. The degradation in the water quality affected the floral and faunal population along with the people dependent on the lake ecosystem. The major environmental problems and their causes in the lake Lakshmital are as follows:

### Deterioration of water quality

The colour of Lakshmital was mostly greenish, due to pollution occurred by algal blooms and raw sewage inflow. Turbidity in the lake ranged from 37.33 to 148.77 NTU, mainly due to silt, organic matter and autochthonous sources from point and non-point source pollution (storm water runoff), directly influencing in the light penetration and affecting the production efficiencies in lakes.

pH values of Lakshmital varied between 7.03 to 7.61, irrespective of all sites and seasons that showed its alkaline nature. At a given temperature, pH is controlled by the dissolved chemical compounds and biological processes in the solution (Chapman, 1996). The dissolved solids mainly consist of sulphates, chlorides, nitrates and phosphates, calcium, magnesium, sodium and potassium.

High total dissolved solids were recorded in Lakshmital that ranged from 502.44 to 758.77 mg/l that indicated the polluted nature of the lake. The suspended solids ranged from 172.88 mg/l to a high of 356.00 mg/l as a result of silt in suspension. The dissolved oxygen levels of the lake ranged from 3.04 mg/l to 4.26 mg/l. The recommended dissolved oxygen concentration for a healthy and ideally productive lake waterbody is 8 mg/l (Wetzel, 1973).

The contents of phosphates were found; ranging from 0.43 to 1.54 mg/l in Lakshmital Lake. The standard is 0.2 mg/l for surface inland water (Chakrapani *et al.*, 1998). Nitrate values ranged between 0.36 and 8.69 mg/l that has exceeded the permissible limit (0.1 mg/l) recommended by NEERI, 1988. Both the parameters are very significant from the point of view productivity in lakes. Thus nitrates and phosphates caused the higher eutrophic conditions in the Lakshmital.

Chemical oxygen demand as a result of pollution is largely determined by the various organic and inorganic materials (Ca, Mg, K and Na etc.). The chemical oxygen demand varied from 663.00 to 2107.22 mg/l that was very high as compared to suggested permissible limits (250 mg/l) for inland surface waters.

## Heavy metal pollution

Trace elements; and especially so-called heavy metals, are among the most common environmental pollutants, and their occurrence in waters, sediments and biota indicated the presence of natural and anthropogenic sources (Forstner *et al.*, 1979). Currently, anthropogenic inputs of metals have exceeded natural sources, Lakshmital is one such example.

Mean metal concentrations of all sites of Lakshmital varied from 0.001 to 0.430 mg/l. Among the analysed metals manganese and zinc were reported in highest concentration while lead and cadmium were recorded in lowest amount. Nickel was below detectable limits.

In aquatic plant species in Lakshmital *Potamogeton zosteriformis* had maximum metal contents and *Phalaris arundinacea* showed the lowest concentration of metals. Metal concentration in the sediments of a water body determines the quality of water (Saikia *et al.*, 1988). In sediments of Lakshmital, manganese and zinc were observed in highest concentration.

Some of the major causes that affected the water quality of Lakshmital are as follows:

- Inflow of untreated sewage from the urban watershed with the effluent coming out from the slaughter house in kasai ki mandi.
- Dumping of waste directly on the fringes of lake and through drains from the nearby communities.
- Addition of organic and inorganic materials through Ganesh Idol immersion (religious activity of Hindu).
- Direct intervention and encroachment of fringe areas.
- Leaching of fertilizers and pesticides from adjacent farms to the lake.
- Pollution by excretory products.

## Reduction of storage capacity of Lake

The lake has become shallow by deposition of silt that can be justified by high concentration of total solids in the Lake Lakshmital. The main causes of siltation are as follows:

- Inflow of monsoon runoff and dry weather flow carrying silt and organic materials from denuded urban watershed.
- Addition of clay and bio and non-biodegradable materials through Idol immersion.
- Organic matter deposition by death and decay of aquatic plants.

## Invasion of aquatic weeds

In Lakshmital four aquatic plants were discovered namely *Potamogeton zosteriformis, Phalaris arundinacea, Eichhornia crassipes* and *Elatine triandra*. The main cause behind their growth was nutrient enrichment of lake due to sewage and different kind of wastes generated by domestic, agricultural and religious activites.

## Socio-economic pressures

From the socio-economic survey of Lakshmital it was concluded that quality of lake has degraded due to anthropogenic activities and lack of maintenance of the lake. One of the major cause was like, being the location of the lake in the urbanized area, about ten percent households were not accessed to modern toilet facilities. Those people used periphery of the lake as open toilet which caused contamination of the water. Open disposal of waste also created unhygienic conditions in the area which caused increased number of mosquitoes and insects and destroyed the aesthetic beauty of the lake by foul odour. Thus all these activities made the lake indirect source of diseases like malaria, diarrhea and water borne diseases.

# Recommendations

## Management and Restoration of Lakshmital Lake

Management of a wetland is the manipulation of an ecosystem to ensure maintenance of all functions and characteristics of the specific wetland type. Appropriates management and restoration mechanisms need to be implemented in order to regain and protect the physical, chemical and biological integrity of wetland ecosystems. In this context a detailed study of wetland management and its implications on the socio-economic aspects is required from biological and hydrological prospective. Restoration means re-establishment of pre-disturbed aquatic functions and the related physical, chemical and biological characteristics (Cairns, 1988; Lewis, 1989).

Based on the conclusions drawn from the present study, an integrated approach for the rehabilitation of Lakshmital Lake is required including following useful and practicable management techniques (**Figure 7.1**):

**(A)** Structural techniques
**(B)** Non-structural techniques

**Structural techniques** for lake restoration include rehabilitation and management of following two components:

**(i)** lake management
**(ii)** Watershed management

### Lake management

The preliminary step that has to be implemented to restore the lake for their long-term sustenance must be carried out under following steps:

***Pollution obstruction:*** Wastewater, solid and semi solid wastes entering into the lake from external sources must be stopped or diverted before the implementation of restoration work.

***Weeds control:*** Control of nuisance vegetation (*P. zosteriformis, P. arundinacea, E. triandra and E. crassipes*), causing eutrophication, must be removed manually or mechanically. Weed infestation can also be controlled by using chemicals like methyl-chlora-phenoxy-acetic acid, hexazinore, etc., and biological control by introducing *Pila globosa* (trophic snail), Chinese grass carp (fast growing fish) etc. that feed on many aquatic plants. But the processes are extremely slow so use of mechanical system involving motorized winches and fixed station movable mesh mechanism (conveyor belt system) would be effective and fast.

***Desilting:*** Dredging of the sediments in the lake to improve the soil permeability and water holding capacity and ground water recharge.

***Cleaning of lake water:*** Water of Lakshmital should be cleaned. Phytoremediation or bioremediation technology or constructed engineered wetlands are cost effective techniques that can be used in the cleaning of lake. A constructed wetland is a water treatment facility that has gained importance in recent years for treatment of lakes. Duplicating the processes occurring in natural wetlands, constructed wetlands are complex, integrated systems in which water, plants, animals, microorganisms and the environment (sun, soil and air) interact to improve water quality. Constructed wetlands mimic nature by mechanically filtering, chemically transforming, and biologically consuming potential pollutants in the wastewater stream. These are shallow pools constructed on non-wetland sites as part of the stormwater collection and treatment system. They provide conditions for the growth of emergent marsh plants. These systems are primarily designed for the purpose of stormwater management and maximum pollutant removal from surface water flows through

physical, chemical and biological mechanisms. They are often used in sequence with a sediment basin or stormwater pond (limgis, 2001).

In the present study metal analysis showed the highest metal accumulation rate in the species, *Potamogeton zosteriformis.* Besides the plant showed closest affinity towards zinc; the metal recorded in highest amount in the Lake Lakshmital. Analysis of metals in other three species also showed affinity with other different metals. So these species can be used through phytoremediation technique to remove metal pollution in the lake.

## Watershed Management

Watershed management is an essential and important part in the restoration programme, in order to prevent inflow of silt, agricultural residues from nearby farmlands and other kind of wastes and long term maintenance of restored lake. Key steps for best watershed management practices for Lakshmital are as follows:

***Fencing:*** A boundary wall of bricks or stones should be constructed on the shorelines of the lake to prevent encroachment in the catchment area.

***Plantations in Buffer Zone:*** To prevent encroachment for human settlements and cultivation and grazing within the lake area, plantation should be done in the buffer area of the lake. The species selection should be of native species; tolerant to both flood and drought conditions and the plants with economic and ecological importance e.g. plants with medicinal values. It will control soil erosion and inflow of silt into the lake.

***Waste Management:*** There should be proper waste management in the periphery of the lake. Municipal Corporation may involve private organizations to achieve the target. NGOs can involve local community to prepare compost from biodegradable waste and promote organic farming. In the present study

survey showed that a higher amount of waste generated in the nearby locality is bio-degradable waste.

***Detention basins:*** At least three detention basins should be constructed for temporarily storing the runoff to prevent sediments loads and pollutants into the lake.

**Non-structural techniques** involve awareness among stakeholders for future management and maintenance of lake. These restoration goals require profound planning, authority and funding along with financial resources and active involvement from all levels of organization. Besides this the participation of ordinary people is an essential and important feature. The task can be achieved through a well coordinated awareness programme involving political and religious leaders, district/city administration, local people, NGOs, Schools, Colleges and Universities. Following types of activities can be done with the present approach:

- Development of database for wetland information and management system through its regular monitoring. Science students at College and University levels may be involved in this work; coordination with academicians is required by the lake managers to achieve the target.
- Awareness campaigns by NGOs, Academic Institutions and Research organizations to motivate the peoples for their participation to keep the lake clean.
- Reforestation of watershed area through involvement of farmers.
- Promotion of organic farming in nearby area to minimize the chemical inflow into the lake.
- Waste management with community participation approach in the fringes of Lakshmital by giving them training.

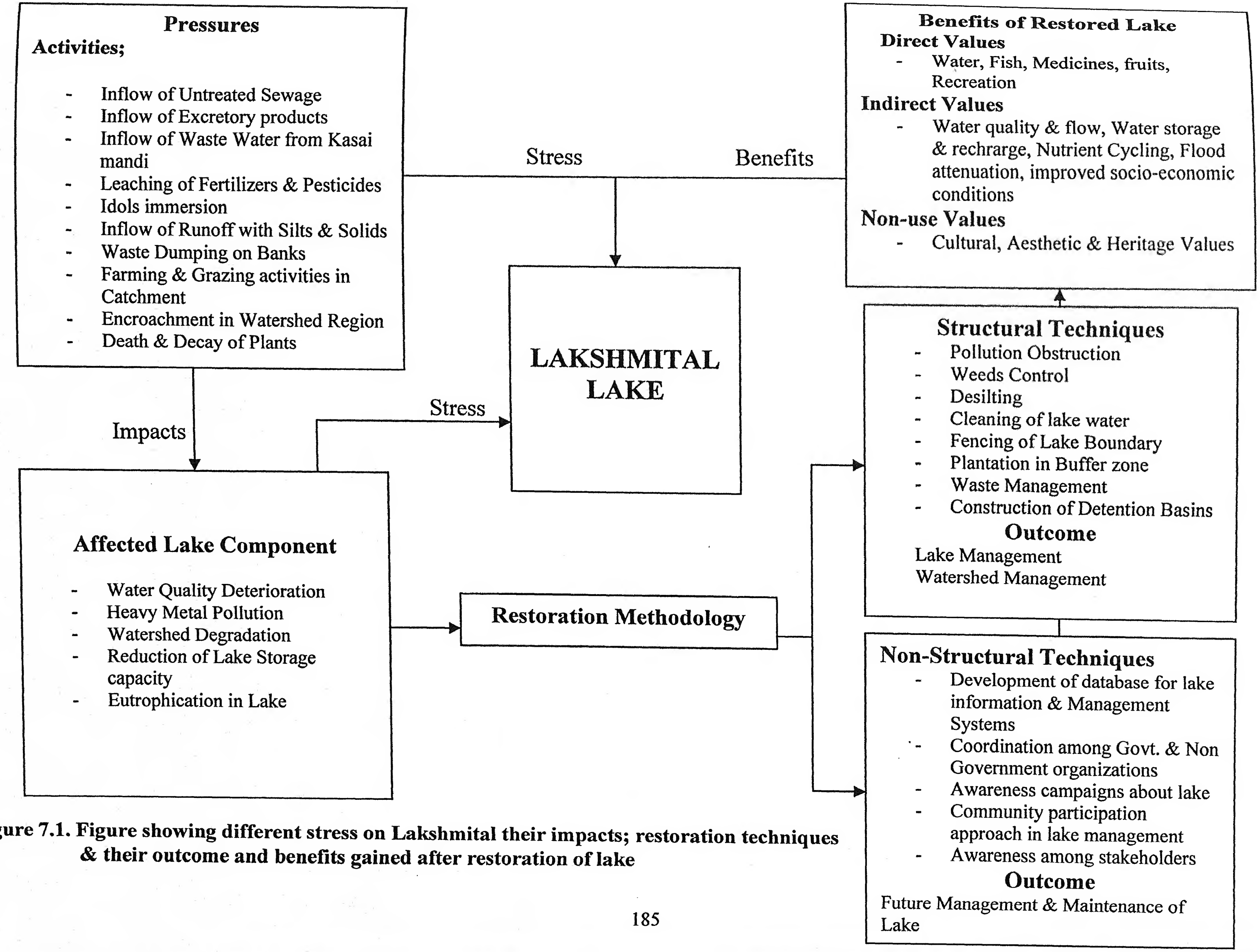



**Figure 7.1. Figure showing different stress on Lakshmital their impacts; restoration techniques & their outcome and benefits gained after restoration of lake**

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# APPENDIX A
# SOCIO-ECONOMIC SURVEY FORM

## A: INTRODUCTION OF THE RESPONDENT

Name: ........................................... Age: ............ Sex: ...........................

Name of Colony:

............................................................................................

## B: DEMOFRAPHIC INFORMATION

Total number of persons in Household: ..............

Age groups: 1-15 years: ...., 16-25 years: ...., 26-50 years: ..., above 50 years: ....

Occupation (s) of Household members:

.......................................................

Total Household income (Rs./year):

...........................................................

## C: DOMESTIC WATER USAGE

Source: Municipal Supply Well Handpump Borewell Lake
Other
Main source:
Alternatives:

Daily water consumption (in liters/day):

100-200 l/day, 210-300 l/day, 310-400 l/day, 410-500 l/day, above 500 l/day

Water usage for Livestock: ......................................... Source: .................

Water usage for other commercial activities: ..................... Source: .................

## D: SOLID WASTE GENERATION

Quantity of waste generation (in kilograms): per day: ........ average of five days:......

Type of waste (Quantity in kg/five days):

Biodegradable: ......................... Non-biodegradable: ..............................

## E: FAMILY HISTORY

How long (in years) family has been living in the area?
10-20 yr: ......... 21-30 yr: ......... 31-40 yr: .......... 41-50 yr: .......... Above 50 yr

For how long (in years) quality of water in the lake has deteriorated?
1-3 yr: ......... 4-6 yr: ........ 7-9 yr: .......... 10-12 yr: ..........

## F: RELIGIOUS AND AESTHETIC VALUES

Have you noticed about a decline in the aesthetic value of the lake? Yes/No

Does the lake play any role in religious activities? Yes/No, Type of activity: ...........

## G: HEALTH EFFECTS:

Has the number of mosquitoes increased over the years with the lake pollution?

(Increase/Decrease/Same):
......................................................................

Have your family suffered from any diseases (related to water quality)? Yes/No

Name of the diseases:
..............................................................................

## H: WILLINGNESS OF INVOLEMENT IN LAKE REHABILITATION

Would you like to involve in the lake restoration activity?

## I: ANY OTHER RELEVANT INFORMATION ABOUT LAKE:

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